SEASONAL CHANGES IN GROWTH, MORTALITY, AND CONDITION OF RAINBOW TROUT FOLLOWING PLANTING

P. R. NEEDHAM AND DANIEL W. SLATER

U. S. Department of the Interior, Fish and Wildlife Service
Stanford University, California

ABSTRACT

The results of experimental plantings of rainbow trout in Convict Creek (California) are presented as related principally to changes in growth, mortality, and condition from month to month over two summer seasons. Survivals are discussed in relation to a food-requirement ratio that has been shown to correlate positively with survival rates obtained.

Survivals of 33 per cent and 56 per cent were obtained over periods of 151 days and 179 days, respectively. Wild fish grew approximately twice as fast as planted fish each season. The coefficient of condition of the planted rainbow trout fell consistently for the first few months following planting. A parallel loss in condition of wild trout occurred but was less marked. ''Conditioning'' of hatchery trout for from 1 to 3 weeks prior to planting had no appreciable effect on survival rates.

INTRODUCTION

The data presented here were obtained from plantings of rainbow trout in 1941 and 1942 at the Convict Creek Experiment Station in eastern California. Experimental stocking of rainbow trout under natural conditions has been conducted there from 1938 to 1942, inclusive. Survival data from 63 test plantings were presented by Needham and Slater (1944). Needham and Rayner (1939) described the techniques and stream sections used.

METHODS

The experiments reported here were carried out to determine the changes in growth, mortality, and condition through two summer seasons. In 1941, the experiment was operated 179 days, and in 1942, 151 days. Stream-section A was used. This section is 310 feet long and has an average width of approximately 7.5 feet.

A total of 168 fingerling rainbow trout (*Salmo gairdnerii*) with an average total length of 3.7 inches were planted each season. Before stocking, the section was pumped dry and all wild trout were removed. These wild fish were weighed and measured, and returned to the section. In 1941, each fish was weighed and measured separately both at the beginning of the experiment and at subsequent removals except in the instances cited below. This treatment caused a somewhat high mortality that year. In 1942, each fish was measured separately as before, but average weights were determined by weighing all individuals in each size group together in water.

Reprinted from Transactions of The American Fisheries Society, Seventy-third Annual Volume, for the year 1943. Published by American Fisheries Society, Investment Bldg., Washington, D. C.

Mortality

As a result of improving the method of handling the fish, survival increased from 33 per cent in 1941 to 56 per cent in 1942 (Fig. 1). The difference between survivals is greater when considered on the basis of food competition. Needham and Slater (1944) have shown that survival of planted trout correlates positively with the ratio of the weight of planted fish to that of all fish, both wild and planted. This relationship is expressed as a percentage ratio. In other words, food requirements are proportional to weight, and a measure of food competition and predation between wild and planted trout in any defined area is given as a percentage ratio which is computed as follows:

$$\text{Food requirement ratio} = 100 \times \frac{\text{Weight of planted fish}}{\text{Weight of all fish (planted and wild)}}$$

The ratio was 65.5 per cent in July 1941 and only 36.5 per cent in the same month in 1942 (Table 1). Consequently, survival should have

Table 1.—*Comparison of food-requirement ratios in Section A, 1941 and 1942*

1941		1942		Difference between 1941 and 1942
Date	Food ratio	Date	Food ratio	
May 3	77.2	May 5	43.7	33.5
June 1	67.4	June 5	40.0	27.4
July 1	65.5	July 5	36.5	29.0
July 31	49.1	August 4	33.8	15.3
August 29	48.5	September 3	45.0	3.5
September 30	46.5	October 3	43.6	2.9
October 29	47.3	....	....	....

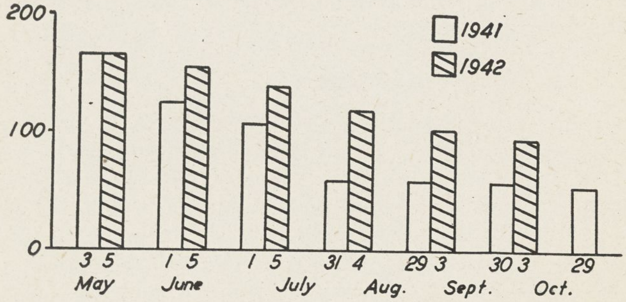


Figure 1.—Number of rainbow trout surviving in Convict Creek

been higher, not lower, in 1941. Inasmuch as the 1942 survival was near the average for 28 planting experiments (Needham and Slater, 1944), it must be assumed that survival in 1941 was below expectations. Trends in the changes in growth and condition do not appear to have been markedly altered despite the abnormal mortality (Figures 2 and 3).

Fish of the 1941 planting grew much faster on the average than did those of the 1942 planting, and the differences in growth rate (Fig. 2) correlate fairly well with the differences in the food-requirement ratios (Table 1).

It is notable from Figure 2 that the rate of growth in August and September of 1941 was less than in the same months of 1942 even though the differences in food-requirement ratios still favored the 1941 planting (Table 1). Probably the method of weighing use in 1941 retarded the growth somewhat in these months. Nevertheless, the close correlation between the food-requirement ratio and the rate of growth in these experiments is further proof of the poor economy involved in planting trout in waters supporting heavy stocks of wild trout.

Growth

Fish of the 1941 planting had nearly twice the average growth increment of those of the 1942 planting due primarily to the relative paucity of wild trout in the former year (Table 2). The increments in both these years are of the same order as those obtained from other experimental plantings in this section in 1938, 1939, and 1940. In this

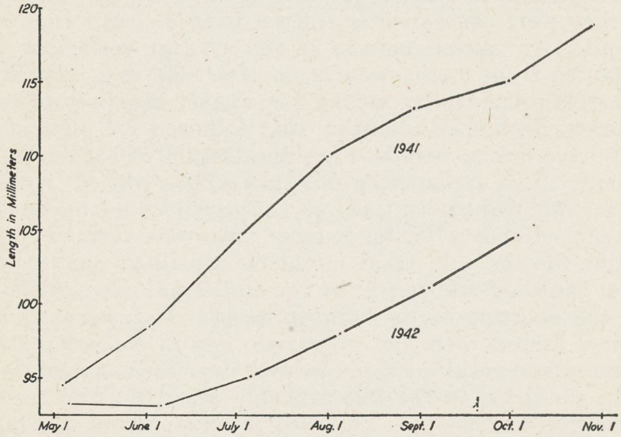


Figure 2.—Growth of rainbow trout in Convict Creek

connection, it is interesting to note that all wild fish in this section had growth increments roughly twice as great as those of planted trout. For example, in 1941 the planted rainbow trout grew an average of 0.96 inches in total length, while 27 brown trout grew from an average total length of 4.47 inches to a length of 6.14 inches, an increment of 1.67 inches. In 1942, the situation was exactly comparable. The planted rainbow trout grew an average of 0.44 inches while the average total length of 38 wild brown trout increased from 4.67 inches to 5.57 inches, or 0.90 inch. The fact that three wild rainbow trout of the year grew

0.84 in in 1942 further confirms the above relations. These differences in the growth increments between planted trout and wild trout are probably the result of the acclimatization process the course of which may be outlined by the changes in condition of the fish (Figure 2).

Water temperatures of Convict Creek expressed as mean daily maximum were 58.6 in 1941 and 59.5 in 1942, over corresponding periods. Thus temperature conditions were slightly more favorable for growth in 1942.

Changes in Condition

The course of changes in the coefficient of condition[1] of trout following planting is easily calculated from the data of these experiments (Figure 3 and Table 3). It will be noted that the progress of events in the two years was very similar. The marked decline in condition of the planted fish occurred one month earlier, however, in 1942, and the drop was nearly twice as great as in 1941. This difference was probably due to the more severe competition obtaining in 1942. In 1941, the initial slight decrease followed by an increase the next month was probably not the true trend. These two observations were based on weight measurements of a sample of 50 fish, less than half the number present; they were consequently subject to more error than the other observations. An initial increase in the average coefficient of condition of planted trout might occur soon after planting, possibly due to early and greater mortality among the weaker fish in poor condition.

The marked decline in condition that followed for planted rainbow trout may have been a result of acclimatization or hardening in their environment. This explanation does not suffice without qualification, however, for the wild brown trout also experienced a marked decline in condition immediately after the hatchery fish were planted (Figure 3). This decline for the wild trout might be explained partly by the experimental handling and partly by the additional competition brought about by the planting of the rainbow trout. It is believed, however, that if these factors were not operative, loss in condition still might have occurred as a result of rapid growth over the summer season. The increase in condition in the fall probably resulted from the more intensive feeding that has been observed to take place in the late fall in high mountain streams in the region of Convict Creek.

The decline in condition of planted rainbow trout was greater than that for wild brown trout. Considering size and species differences, the brown trout would normally have shown lower, rather than higher, coefficients of condition (Embody, 1937). The coefficients of condition of the planted rainbow trout were higher than those of the brown trout for only approximately one month in 1942 (Figure 3).

---

[1]The coefficient of condition, commonly known as the condition factor, is a measure of the relative plumpness of a fish in relation to its length. It was used by Hecht (1916), who gave the following formula for the computation of the coefficient a:

$$a = \frac{100 \times \text{weight in grams}}{(\text{length in centimeters})^3}$$

TABLE 2.—*Changes in total length in inches of wild brown trout and planted rainbow trout during the 1941 and 1942 seasons*

1941			1942		
Date	Wild brown trout	Planted rainbow trout	Date	Wild brown trout	Planted rainbow trout
May 3	4.47	3.71	May 5	4.67	3.67
June 1	4.97	3.88	June 5	4.91	3.67
July 1	5.19	4.11	July 5	5.24	3.74
July 31	5.50	4.33	August 4	5.41	3.86
August 29	5.80	4.46	September 3	5.54	4.00
September 30	6.02	4.53	October 3	5.57	4.11
October 29	6.14	4.67	....	......	......

TABLE 3.—*Changes in coefficient of condition of wild brown trout and planted rainbow trout during the 1941 and 1942 seasons*

1941			1942		
Date	Wild brown trout	Planted rainbow trout	Date	Wild brown trout	Planted rainbow trout
May 3	1.291	1.180	May 5	1.209	1.164
June 1	1.223	1.154	June 5	1.127	1.190
July 1	1.141	1.189	July 5	1.115	1.081
July 31	1.160	1.150	August 4	1.119	1.031
August 29	1.122	1.097	September 3	....	1.036
September 30	1.100	1.113	October 3	1.082	1.055
October 29	1.128	1.161	....	....	....

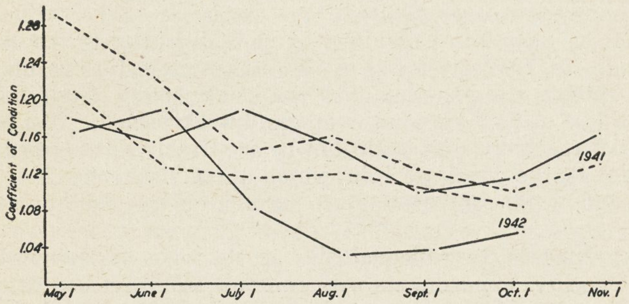


FIGURE 3.—Changes in coefficient of condition of trout in Convict Creek. Rainbow trout—solid line; brown trout- - -broken line.

It must be concluded from these observations that trout planted in streams lose condition during the first 3 or 4 months after planting. This loss doubtless includes that which might normally occur during the summer growth season, but it probably resulted primarily from acclimatization and only secondarily from the competition with wild trout.

EXPERIMENTAL "CONDITIONING" PRIOR TO PLANTING

The term "conditioning" as used here implies treating the hatchery fish in such a way as to prepare them physiologically for the natural environment into which they are to be planted. To be effective, the process probably should be one of gradual change from the hatchery environment to the natural environment over a period of time varying with the degree of change involved in the transfer. Such a process is impractical in most cases because it would entail too great an expenditure of time and funds. Experimental conditioning was studied at Convict Creek in 1941 and 1942. In 1941, conditioning consisted of holding the fish in a section of natural stream for one week prior to planting. In 1942, the period was lengthened to three weeks, and the trout were held in dirt-bottom pools built at the side of the main creek. After conditioning, equal numbers of conditioned and unconditioned fish were planted in the same section of stream to test survival and growth under identical ecological conditions. Each of these experiments was duplicated in a separate stream section each year so that a total of 12 plantings was made over the two seasons covered.

One paired experiment was carried out each year with brown trout fingerlings (around 1.4 inches, total length). Two paired experiments were made each year with rainbow trout—one with small (around 1.5 inches, total length) and one with large (around 3.5 inches) fingerlings. A total of 484 small fingerling brown trout and rainbow trout were used in each planting in 1941. In 1942, 362 small rainbow trout and 436 small brown trout were in each planting. In each year, 70 large rainbow trout were planted.

In 1941, no record was obtained of mortality during the conditioning period. In 1942, no losses of the larger fingerling rainbow trout occurred during conditioning, but the small brown trout fingerlings suffered a loss of 24.7 per cent over the 3-week period. The mortality of the small rainbow trout could not be accurately determined because the screen at the head pool in which these fish were held became plugged and water ran around it, permitting the fish to escape upstream.

The experiments were inconclusive on the basis of the survivals obtained. The 1941 experiments with rainbow trout demonstrated either no difference between the survival of the conditioned and the unconditioned trout or a slight advantage in favor of the unconditioned ones. The 1942 experiments with rainbow trout gave a very slight advantage to the "conditioned" fish in three plantings and a slight advantage to the unconditioned ones in one planting of large fingerlings.

The results of experiments with brown trout were more consistent. In the two 1941 plantings the survival of unconditioned fish was the greater by 7 and 10 per cent. The two 1942 plantings showed advantage to the conditioned fish of 8 and 8.5 per cent.

As was stated earlier, 24.7 per cent of the brown trout were lost during conditioning in 1942. During the course of one experiment, another mortality of 61.9 per cent occurred among the unconditioned fish planted and 53.2 per cent among the conditioned fish. In the other section, mortalities were 40.4 per cent and 32.1 per cent, respectively.

Losses during conditioning plus those following planting were greater than if the fish had been planted directly without conditioning.

It can be concluded that conditioning as attempted here was an uneconomic process and was not justified by the results obtained. Further studies of conditioning must be made before its real value can be determined. In any case conditioning should be supplemented by carefully administered planting. In the planting the fish should be so distributed as to break down the gregarious habits established at the hatchery. In addition, the usual recommendations as to the selection of favorable conditions of food, shelter, temperature, and other factors should be followed.

Further evidence bearing on the efficacy of conditioning is given by unpublished data of Dr. H. S. Davis from an experiment conducted in North Creek near Leetown, West Virginia. Rainbow trout of around 9 inches, total length, were used and conditioning encompassed several months. ''The fish . . . were conditioned . . . in sections of the natural creek beds, which were screened to prevent escape of the fish. These fish were fed a small amount of artificial food, but depended largely on natural food which they foraged for themselves.'' A total of 504 hatchery fish and 509 conditioned fish were planted at the same time and under the same conditions in North Creek.

The results of this experiment show definite advantage both for and against conditioning depending on the result desired. Fewer of the conditioned fish were taken by anglers in the season immediately following the spring planting (27 per cent as compared with 42 per cent of the unconditioned fish) and they more nearly resembled wild fish in appearance and habits than did the fish planted directly from the hatchery. These results indicate an advantage for conditioning where the object of planting is to build up a self-sustaining resident stock. But if the object of planting is to provide large, legal-sized trout for immediate catching in order to alleviate the effects of over-fishing, conditioning would defeat the purpose.

Summary

1. Changes in growth, mortality, and condition of 168 rainbow trout following planting were determined at regular intervals during the growing seasons of 1941 and 1942.

2. The survival was 33 per cent in 1941, and 56 per cent in 1942. Handling caused a heavier than normal mortality in 1941.

3. Growth of fish planted in 1941 was nearly twice as fast as growth of those planted in 1942 because of less competition from wild fish. Wild brown trout grew, roughly, twice as fast as the planted rainbow trout.

4. The coefficient of condition of hatchery trout fell during the first 3 to 4 months following planting during the initial period of harden-

ing in a new environment. A parallel but less pronounced loss in condition of wild trout was noted.

5. Considering the methods and size of fish used, hardening or conditioning of trout for periods of 1 week and 3 weeks, respectively, was uneconomical and not justified in terms of resulting survivals.

Literature Cited

Embody, G. C.
1937. Weight-length relationship of hatchery reared trout. Fish Culture, Vol. 3, No. 2, pp. 19-38. N. Y. State Conservation Dept.

Hecht, Selig.
1916. Form and growth in fishes. Journ. Morphol., Vol. 27, pp. 379-400.

Needham, P. R., and H. John Rayner
1939. The experimental stream, a method for study of trout planting problems. Copeia, 1939, No. 1, pp. 31-38.

Needham, P. R., and D. W. Slater
1944. Survival of hatchery-reared brown and rainbow trout as affected by wild trout populations. Jour. Wildlife Management, Vol. 8, pp. 22-36.

SURVIVAL OF TROUT IN STREAMS

Paul R. Needham

Oregon State Game Commission
Portland, Oregon

Reprinted from Volume 77 (1947), Transactions of the American Fisheries Society.
Published 1949. Printed in U.S.A.

SURVIVAL OF TROUT IN STREAMS

PAUL R. NEEDHAM [1]

Oregon State Game Commission
Portland, Oregon

ABSTRACT

In spite of extremely heavy expenditures for rearing of hatchery fish, the angling continues to decline. Millions of fish are wasted each year because of lack of facts on how best to utilize properly the product of hatcheries.

Survival studies have indicated that under natural conditions, wild brown trout suffer tremendous natural mortalities amounting to 85 percent in the first 18 months of life. Overwinter mortalities averaged 60 percent over a 5-year period. Variable survival conditions rather than the number of young produced in any year, determine the number of fish that later reach catchable size.

Survival studies of hatchery-reared trout indicated heavier losses than with naturally spawned fish. Creel-census returns from a number of different waters are presented to support this fact.

The conclusion is reached that the angling public must be made aware of the basic economics of hatchery operation, its costs, successes, and failures in order that the field of fishery management again may move ahead.

INTRODUCTION

Millions of dollars are spent annually on the rearing and planting of trout throughout the United States. In spite of these efforts, the angling continues to decline. Most states since the war have suddenly found themselves facing new hordes of customers who are placing a serious drain on their fish resources. The net effect of the increased pressure is less fish per individual. With more fishermen to share the catch, there are less fish to be had per person. This condition has brought protest and criticism to conservation departments and the cry, as usual, is for larger and better fish hatcheries.

Heavy losses of hatchery-reared fish in streams following planting have been made known by much fact-finding work over the past 10 years. Millions of fish have been planted in waters to which they were unsuited and in which the effort was largely wasted. For example, in the three Pacific Coast states, millions of eastern brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) were planted in coastal waters without evident result. In many of the inter-mountain states, exotic species like eastern brook and brown trout, although doing very well in certain waters, have frequently failed because of lack of knowledge of where to plant these species. In many waters, native stocks still continue to bear the

[1] Now Professor of Zoology, University of California, Berkeley.

brunt of the angling in spite of continual heavy plants of exotic hatchery fish.

The demand for larger and better fish hatcheries is only natural. The public witnessed the stocking of thousands of barren waters throughout the United States and concluded from the fine fishing produced that the answer to the present scarcity of fish must be more fish hatcheries. The average sportsman still believes this firmly and we have no one to blame but ourselves for his attitude. We looked upon hatcheries as the simple, easy panacea for all our angling ills for years and spread the dogma far and wide.

We know fairly well now what to expect in many types of waters in terms of returns to the creel from a planting of any given number, size, or species of fish and it is my purpose here to present a summary of facts pertaining to the survival of both wild and hatchery fish planted in streams. It might be well first, to consider survival problems in populations of wild trout in order to obtain a basis for comparison with survival of hatchery-reared fish.

Survival of Naturally Propagated Brown Trout

In work by Needham and Slater (1945) done at Convict Creek in eastern California over a 5-year period, it was determined that on the average, each naturally spawned yearly brood of brown trout decreased about 85 percent in the first 18 months of life. In other words, out of every 1,000 2- to 3-inch fingerlings produced annually, only some 150 survived to become yearlings. This fact alone indicates that extremely heavy mortalities occur in wild trout populations.

From this same work, it was also found that the average overwinter loss of all brown trout, regardless of size, was 60 percent and was evidently directly correlated with severity of winter conditions. Convict Creek is a typical, small, high-mountain trout stream averaging about 15 feet wide. The area in which the work was done lay in a meadow at an elevation of 7,200 feet. The stream was, therefore, subject to severe climatic conditions in the winter. Winterkills of trout were caused by heavy snow and ice conditions. In one instance, over 250 trout were found smothered to death under a single snow drift that had broken off into the stream bed. On waters draining areas of milder winter climates, heavy floods doubtless cause parallel heavy mortalities.

Over the 5-year period of the work on Convict Creek, natural reproduction alone contributed an average of 2,750 fingerling brown trout per mile of stream each year (range from 4,905 in 1940 to 1,714 in 1939). Only 16 percent of the 1939 fingerlings were lost over the winter of 1939–40 whereas in contrast, 85 percent of the 4,905 fingerlings were lost over the winter of 1940–41. In terms of fish available to anglers, the 1939 brood, by reason of its higher overwinter survival, contributed more fish to anglers than the 1940 brood which started with peak numbers but which was decimated by environmental factors. Variable survival conditions, rather than the number of young produced by natural spawning in any given season, largely determines the number of fish that later reach catch-able size.

It was determined also that the survival rate of wild brown trout fingerlings was much higher than that of fish of the same species planted from hatcheries.

Wild populations of brown trout were studied in two closely adjacent sections of Convict Creek, one of which was open to fishing while the other was closed to angling. Fish populations were removed by diversion of the water and pumping the stream bed dry by means of a small portable pump.

The fished section averaged only 3,818 trout or 83.3 pounds per mile, while the section closed to angling averaged 5,438 fish or 360.3 pounds per mile. If the population of the section closed to fishing is assumed to be a maximum standing crop, it would be necessary to plant 277 pounds of trout per mile to bring the population in the open section up to that of the closed section. This poundage would be equivalent to about 2,700 6-inch fish per mile and theoretically, at least, stocking as heavy as this would not be in excess of the numbers that could be supported naturally by Convict Creek.

With the annual natural production of young so tremendous and with the heavy subsequent losses under natural conditions, it is apparent that trout angling is definitely a "luxury" trade. Each fish that survives to the angler's creel represents the end product of a considerable stream area, or to put it another way, the lone survivor of many hundreds of other fish that never matured to be caught. The older and larger the fish caught, the higher are the losses of fish behind that individual. It is time that we inform the average fishermen concerning some of these things if we are to get their cooperation in killing less fish so they can catch more fish.

Another interesting fact to come out of the Convict Creek work was that a survival of only 30 female brown trout of spawning age per mile of stream would be required to produce the greatest number of young fish per mile that this stream could support in any year. Herein lies a strong argument for angling regulations which will assure adequate escapements of brood trout necessary for the recruitment of naturally spawned stream stocks.

Survival Data on Hatchery-Planted Fish in Streams

It might be well to review for a moment some of the available information on western trout streams wherein attempts have been made to determine survival following planting and to present ratios of the number surviving compared to numbers planted.

The 1938 creel-census returns from the Kern River in California reported the capture of 5,579 rainbow trout, 73 brown trout, and 58 brook trout. Between 1934 and 1938, 275,000 brown trout had been planted in the stream. On the basis of the 1938 returns, the ratio of number planted in previous years to the number taken in 1938 was 1:3,767. In Squaw

Creek in northern California between 1930 and 1936, 130,000 brown trout had been planted. In 1937, when a creel census was made on that stream, 2,497 rainbow trout were taken but only 7 brown trout and no eastern brook were taken. The ratio of brown trout planted to numbers caught was 1:18,571 (Randle and Cramer, 1941). Here again is the old story of native stocks maintaining the burden of the angling in spite of heavy plantings of non-native species. Wild, naturally spawned rainbow trout furnished over 97 percent of the fish caught by anglers in Squaw Creek.

Needham and Slater (1944) carried on survival experiments with hatchery-reared fingerling brown trout at Convict Creek and obtained a survival of 63.7 percent for fingerlings averaging 1.2 to 1.5 inches long. Larger rainbow trout fingerlings ranging from 2.8 to 3.7 inches in length under more severe competition by wild trout produced a gross survival of 46.6 percent. These results were obtained over the summer growing season only when ideal water conditions prevailed for the growth and development of the fish. But even so, losses ranged from about 45 to 65 percent in periods varying from 89 to 151 days. Add overwinter losses to summer losses, and it is apparent that plantings of such fish in mountain streams are largely ineffectual.

These results do not indicate futility of plantings any more strongly than those obtained by many workers. Survivals of less than 1 percent for 1- to 3-inch fingerlings are the usual story while, under ideal conditions, plantings of legal-sized fish during open seasons may produce returns as high as 80 percent. I have no intention here of citing the work of various individuals and agencies that have been studying this problem. Here I am concerned more with the applications of existing facts than with the means of discovering them. Schuck (1948) gave an excellent review of the whole problem of the survival of hatchery-reared trout. It is clearly indicated in his paper that one major reason for the low recoveries is the inability of hatchery trout to survive for any length of time under natural stream conditions. He pointed out that one principal cause for this high mortality may be improper methods of feeding and rearing in hatcheries and recommended a critical evaluation of all hatchery procedures with a view toward modification of those which limit a trout's ability to survive.

It is true that improvement of our hatchery techniques is one of our major concerns, but we have a parallel problem in public relations. For years we have been blithely putting out lists of streams and lakes stocked. It is time now that we consign these lists to the waste basket and begin to educate the public as to what we can and cannot do with hatchery fish. As was pointed out by Taft (1947), "The principal barrier to further progress is the unreasoning and abiding faith of our customers in the planting of fish under all conditions, at all times, and in every water." Further progress will become possible only when the facts are made known to the fishing public and applied in our management programs.

We all know we are going to need fish hatcheries. The real problem is one of using the product in such a manner as to get the greatest possible return to creels of the anglers at the least possible cost. With our rearing operations now costing us around 50 cents per pound of fish for food alone, it would seem desirable to spend somewhat more money on fact-finding work to learn what we are getting for our money and reduce a bit the rearing and planting operations where the values are questionable. It seems that some money now going into propagation might well be spent on such items as stream and lake improvements, creel-census work, and research. The Oregon Game Commission is obtaining excellent cooperation from a number of sportsmen's clubs in creel-census work. The anglers themselves are glad to help and such work does a lot of good in educating the fisherman on the facts with respect to survival of trout in terms of cost-and-catch figures. If we can rear and plant legal-sized trout for say 20 cents apiece and if only 25 percent survive to be caught, the end cost becomes 80 cents each in the creel. This is expensive business. On the other hand, if by better rearing and planting under conditions more conducive to survival, an 80-percent return is obtained, the end cost in the creel is reduced to 25 cents per fish. Even this cost per fish would permit catching only 12 such fish on a 3-dollar resident license fee. If more than 12 such fish are taken, it is done at the expense of other anglers.

It is a well known fact fully demonstrated by creel-census studies, that over 80 percent of the fish taken in any given watershed are taken by less than 25 percent of the anglers. Since this is true, reduction of seasons and of bag limits to say a 60-day season and five fish, hurts the average fisherman very little; the person it really affects is the expert, the rod artist who can take fish easily at almost any time under difficult conditions. Herein lies a potent argument for more severe restrictions to secure greater spread of available fish among greater numbers of anglers.

To get back to our main thesis, the basic economics of hatchery costs and survivals must be understood by the license holders, and once they understand the problem, the field will again move forward.

There are many opportunities for management by such means as stream and lake improvement, trash-fish control, improvements to aid natural propagation, and fertilization of lakes to increase fish production. Once tested methods are available and once we have our hatchery programs in proper balance with other activities, fishery management will become a reality.

It is high time that we examined our entire fish-cultural programs with a critical eye toward applying facts presently available. Fish hatcheries are not the whole answer; they are only part of the answer, and the most expensive part at that. We must place the facts before the sporting public so that they, too, will begin to understand the nature of the critical problems facing us in the maintenance of game-fish populations. If the public is informed, it will help, instead of hinder, the application of new discoveries. No program can succeed without public support.

Literature Cited

Needham, Paul R., and D. W. Slater
1944. Survival of hatchery-reared brown and rainbow trout as affected by wild trout populations. Jour. Wildlife Man. Vol. 7, pp. 18–23.

Needham, Paul R., James W. Moffett and D. W. Slater
1945. Fluctuations in wild brown trout populations in Convict Creek, California. Jour. Wildlife Man. Vol. 9, pp. 9–25.

Randle, Allan C., and F. K. Cramer
1941. The Squaw Creek Test Stream. Calif. Fish and Game, Vol. 27, pp. 172–184.

Schuck, Howard A.
1948. Survival of hatchery trout in streams and possible methods of improving the quality of hatchery trout. Prog. Fish-Cult., Vol. 10, No. 1, pp. 3–13.

Taft, A. C.
1947. Maintenance of angling in California. Trans. Twelfth N. Am. Wildlife Conf., pp. 254–257.

Reprinted from Transactions of the Fifteenth North American Wildlife Conference, March 6, 7 and 9, 1950. Published by the Wildlife Management Institute, Wire Bldg., Washington 5, D. C.

ARTIFICIAL PROPAGATION OF GAME FISHES—LOOKING FORWARD

Paul R. Needham
University of California, Berkeley, California

Within the past few years a great unrest has developed in fish and game councils much of which is caused by problems relating to the artificial propagation of both fish and game. This unrest has caused the administrative bodies concerned to reach out beyond their state borders in many instances seeking the advice of those who could aid them in an analysis of their problems and recommend remedial measures. Survival data on game birds or fish following release were slowly being revealed from much research and the results were anything but encouraging. The net costs in terms of a bird in the bag or fish in the creel were impressive if not staggering.

As a result of new evidence presented, rearing and restocking programs have been slowly modified in an effort to improve the net return per dollar expanded in propagative efforts. It is my purpose here to summarize briefly some of the major findings with respect to recovery of hatchery trout when planted in either lakes or streams and to compare these with the survival of wild, naturally propagated fish. Figure 1 presents expected percentage recoveries plotted against size of fish planted in lakes. Figure 2 gives the average survival history of four broods of ''O'' age group (less than 1 year old) wild, naturally propagated brown trout as determined by Needham, Moffett, and Slater

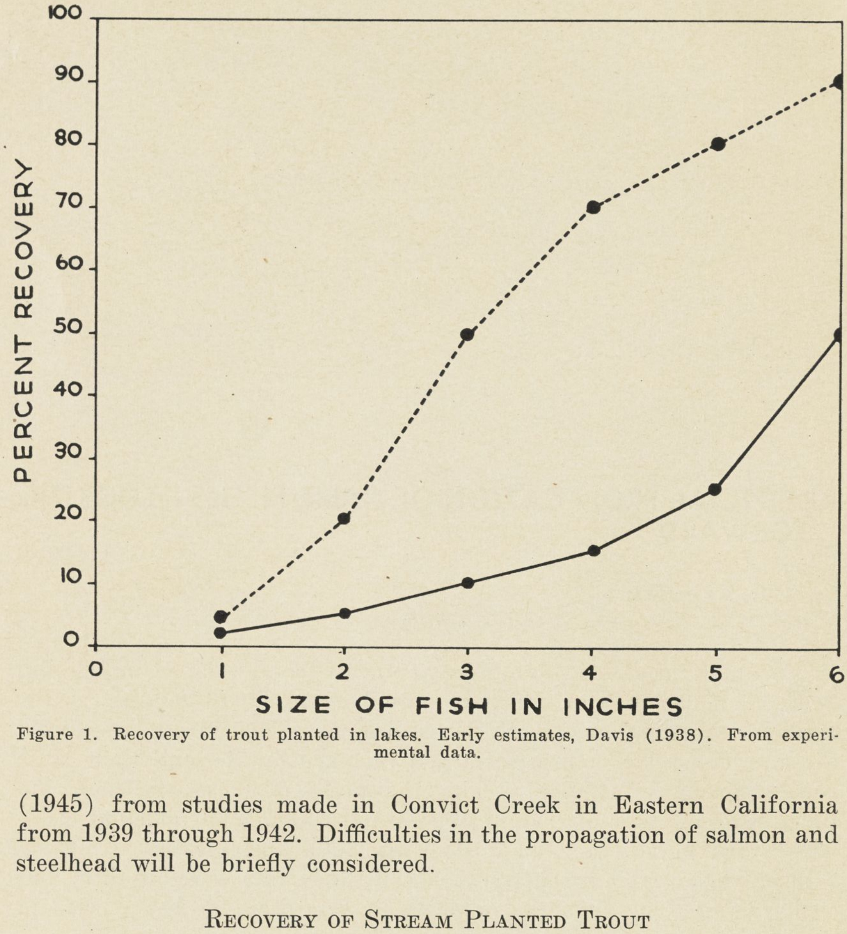


Figure 1. Recovery of trout planted in lakes. Early estimates, Davis (1938). From experimental data.

(1945) from studies made in Convict Creek in Eastern California from 1939 through 1942. Difficulties in the propagation of salmon and steelhead will be briefly considered.

RECOVERY OF STREAM PLANTED TROUT

In considering trout recovery data, it is obviously necessary to consider the time when each planting was made, the species, sizes, and numbers of fish that were planted as well as the type of stream and general ecological conditions obtaining in each. The bulk of recovery data from stream plantings are contained in the following papers which cover these points, and for the sake of brevity they are listed herewith without direct reference: Nesbit and Kitson (1937) Hoover (1938), Hazzard and Shetter (1938), Surber (1940), Randle and Cramer (1941), Smith (1940), Shetter and Hazzard (1940), Holloway and Chamberlain (1942), Gee (1942), Chamberlain (1942), Williamson and Schneberger (1943), Needham and Slater (1944), Smith and

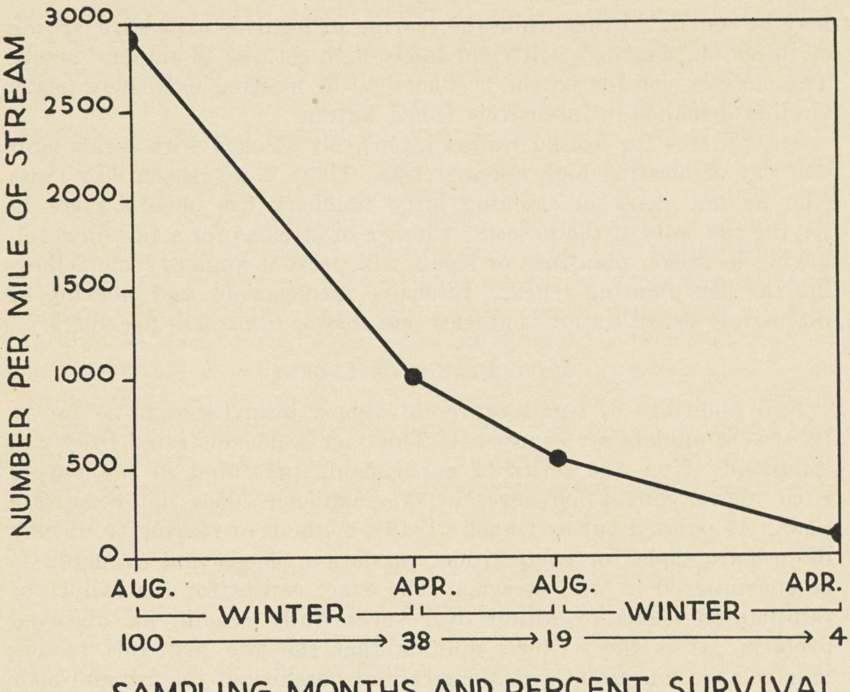


Figure 2. Survival history of wild brown trout, "O" Age Group, Convict Creek, 1939-42.

Smith (1943), Shetter (1944), and Thorpe, et al (1947). In addition to these, the writer has drawn on certain unpublished materials that have been made available to him in arriving at the summary presented.

The data can best be grouped and considered under the following categories: (1) Spring or in-season plants of legals, (2) fall plants of legals, and (3) spring, summer and fall plants of small fingerlings of less than legal length. While much of the data presented in the above papers are not strictly comparable and many variables are apparent, nevertheless a close examination permits drawing certain conclusions. Admittedly further experimental work may require a revision of the ideas presented, but it is doubtful that new information will drastically change the facts as they now stand.

RECOVERY OF SPRING OR IN-SEASON PLANTINGS OF LEGALS

While recoveries have been quite variable, a few running less than 5 per cent, the great bulk of the recoveries reported range close to 50 per cent, with some recoveries of over 80 per cent being reported. It may be concluded that while the rearing of legals is expensive, spring or in-season plantings will yield fairly high returns to anglers' creels. This may be considered the best method of meeting extremely heavy angling demands in intensively fished waters.

Special fees for fishing waters intensively stocked with legals offer one way of meeting high rearing costs. There is no reason why those who do not share in catching large hatchery fish should share in paying the costs of the process. Closure of streams for a few days following in-season plantings of legals will prevent anglers from following the fish planting trucks. Intensive management and stocking of intensively fished waters is at least one answer to present pressures.

Fall Plants of Legals

Fall plantings of legals represent almost total losses in so far as returns to anglers are concerned. This fact is demonstrated fully and completely from the series of experiments presented in the papers cited above, and I am sure, to this audience, does not constitute news. As pointed out by Chuck (1948), methods of rearing trout may ill prepare them for competition, predation, floods and droughts to be encountered in wild streams. The exact causes for the failure of fall-planted legals to winter over successfully remain an unsolved problem. It is the writer's opinion that the two principle factors involved are concerned with the strain or heredity of the fish and poor physiological adaptation to withstand the hazards of natural environments.

Spring, Summer, and Fall Plantings of Fingerlings in Streams

Recoveries in this group are extremely low; in fact, almost as poor as is found with fall-planted legals and represent a large economic waste. As a case in point, one fall planting of some 30,000 three- to four-inch rainbow in a rugged, cold mountain stream produced exactly nine fish to creels (unpublished). If the cost of rearing the entire lot is charged against the nine fish recovered, the net cost per fish was over $50.00 each. This type of planting is no worse than many that are still being made with great regularity because of pressure from anglers. Allotments of small fish to be planted in cold mountain rivers and streams are still being made with punctual regularity from year to year despite the published record of the utter futility of this process. Hazzard (1945) writing of Michigan streams says, "It is concluded that in the majority of Michigan streams, enough or more than enough young are produced to fully seed the waters with all the fish they can feed and house."

There is another fact of importance in relation to wastage of plants of small fish in cold mountain or hill streams. Usually continual plantings of exotic, non-native trout have no effect whatsoever on catches, native species continuing to provide the bulk of fish taken from natural spawning. Cases in point are the stocking of brown trout into rainbow waters and eastern brook in western steelhead streams.

Abandoning such plants of small fish would save millions of dollars over the country as a whole and the monies thus saved would be used for rearing larger numbers of legals, habitat improvement, fish screens, ladders, and other badly needed items. It would seem far more efficient to rely on natural propagation in most open streams, reserving legals for stocking only where special conditions warrant. To implant the idea of ''sport'' fishing in anglers' minds in place of their usual objectives of ''meat'' or ''limit'' catches would spell a new era in fishery conservation. To catch more fish, less must be killed for the bag, and reduced limits hurt no one from a sport-fishing standpoint. As Seth Gordon (1950) has so aptly said, ''The only solution to maintenance of trout fishing of a reasonably satisfactory quality is to kill fewer trout.''

Recoveries of Trout Planted in Lakes

As a general rule, recovery of trout planted in lakes is higher than it is in streams. One major reason for this no doubt lies in the fact that lake environments present more stable living conditions less subject to the seasonal hazards of streams. Lakes possessing downed timber and weed beds in shallow water likewise provide more escape shelter. Lakes are usually richer in foods and have more stable temperature conditions. For these reasons and others, lakes will produce more pounds of fish per acre of water area than streams.

Examination of fishery literature reveals considerably fewer reports on plantings of marked trout in lakes. Papers covering this subject are as follows: Needham (1937), Needham and Cliff (1938), Davis, et al (1938), Shetter and Hazzard (1940), Needham and Sumner (1941), Vestal (1943), and Wales (1946). Here, too, direct reference to the above papers will be omitted in favor of a brief summarization of the general over-all facts determined.

Recoveries of legal-size trout planted in the spring or during open angling seasons in intensively fished, accessible lakes will usually run from 40 to 60 per cent of total numbers planted. On the other hand, plantings of 2- to 4-inch fingerlings will usually produce returns ranging from 2 to 5 per cent. Even these low recovery rates are still higher than those obtained with the same species and sizes planted in streams. For this reason some Western States are tending toward the policy of stocking lakes more heavily than streams with small fingerlings.

In Figure 1 is presented a tentative curve indicating the recovery rates of trout that may be expected when using fish of various lengths planted in lakes. This represents the rounded figures from various experimental data referred to above. It can be considered only as approximate at best, but it is based on presently available facts. In light of future studies, it will doubtless require revision.

Examination of recoveries from lake plantings indicate that there is a much greater survival of fish to subsequent angling seasons following planting than from fish planted in streams. In stream-planted fish the carry-over is negligible, few fish remaining to be caught in their second or later seasons following planting.

Another point of importance derived from such experimental plantings is that the take of wild, naturally propagated trout tends to remain fairly constant from year to year regardless of the number and size of hatchery-reared fish that are planted. A few workers claim that heavy plantings of legals so step up the fishing effort that the kill of wild breeders is also increased to the detriment of the stream concerned. Evidences from experiments conducted over periods of 4 or 5 years on the other hand indicate a fairly even annual take of wild fish with a sufficient escapement of wild spawners to seed the stream properly each year.

By way of comparison, studies on the survival of naturally spawned, wild brown trout populations (Needham, et al, 1945; Needham, 1947) have indicated tremendous parallel heavy losses in high mountain streams subject to severe winter conditions. Over a 5-year period, the average annual hatch or brood of young fish was reduced over 62 per cent in their first 12 months of life (Figure 2). After 20 months' time the average annual reduction was over 95 per cent. These studies indicate variable environmental conditions rather than numbers of young produced, and largely determine the numbers that survive from year to year. With wild brown trout averaging 15 per cent survival into their second year, it is not surprising that hatchery-reared fish of the same size produce stream recoveries of usually less than 1 per cent. Wild brown trout are extremely adaptable, hardy, and apparently well fitted for combating adverse conditions. Probably rainbow or eastern brook would prove equally hardy under conditions to which they are well fitted.

Another proof of the more favorable survival of wild trout is that they grow much faster than hatchery-reared trout. Curtis (1934) reports this with golden trout, and Needham and Slater (1943) found that wild trout grew twice as fast as the trout planted in 1941 and 1942 in the Convict Creek experimental stream sections.

Hatchery Propagation of Salmon and Steelhead

With these forms a different set of conditions are imposed. The maintenance of open migratory routes is basic to the welfare of all anadromous species. The artificial propagation of salmon has developed rapidly within the past few years for two reasons. First, certain species of these fish are easier to cultivate than trout, and second, Grand Coulee and Shasta Dams caused the initiation of large-scale fish-cultural experiments in an effort to save the runs blocked by these dams. Parallel studies are now going forward by both federal and state agencies who are seeking ways and means to ameliorate the harm that will be caused to sea-running fishes by the mammoth, basin-wide water-development programs under study. Only time will tell whether we can have both dams and migratory fishes. In its present state of development at least, artificial propagation could never be substituted for the hundreds of miles of natural spawning, gravel areas in western streams where these fish are now breeding. It might, and doubtless is supplementing natural propagation in small degree. But from the standpoint of the long pull, our main reliance must be placed on natural propagation coupled with open migratory routes.

Artificial propagation of spring-running races of salmon and steelhead is difficult because of the fact that many adults die during the long holding and ripening periods prior to the time when the fish are spawned. Rearing of young salmon is comparatively easy once good eggs are secured. Rearing of steelhead in hatcheries, on the other hand, is fraught with many difficulties aside from those related to food and parasites and diseases. There is a tendency now in the Pacific Coast States toward reduction of fish-cultural efforts with respect to steelhead, and it is likely that within a period of years, reliance will be placed almost entirely on natural propagation to maintain these fish. Even so, some culture of them will be required to obtain fish for stocking barren streams or streams in which accidents or dams have destroyed former runs. If natural propagation is aided and abetted with fish screens and ladders, clean up of pollution, and other improvements, plus proper control of the harvest, we may still be able to preserve a few scattered races of these magnificent fish for future generations.

Hatcheries represent factories. The more units of goods produced, the less each costs within limits. To continue the economic waste involved in ill-timed, hopeless plantings is not the hatcheryman's fault; it is the fault of the biologist in not making the recovery story alive, vivid, and clean-cut. We know fish hatcheries will always be a basic requirement to the conduct of well-rounded stocking and management programs. But to secure popular support to cut *out* the bad and retain the good from artificial propagation, the public must be made fully aware of the basic economic and biological facts underlying the survival of hatchery-reared fishes.

The widespread belief in hatcheries by the general public as a cure-all for our angling ills is a brake on the wheel of progress in fish culture and management. The fine work done by a host of workers dealing with such warm-water fishes as the basses, sunfish, and catfish, have clearly outlined the proper role of fish culture for these fish. We need an equally clear outline for its proper role with cold-water fishes. Much fact-finding work remains to be done to clearly define its proper place in a scheme of management. The unrest in the fish and game councils where the criticisms fall can only be quieted with facts, not further guess-work.

LITERATURE CITED

Chamberlain, Thomas K.
1942. Research in stream management in The Pisgah National Forest. Trans. Amer. Fish. Soc. Vol. 72. pp. 150-176.

Curtis, Brian
1934. Golden trout of the Cottonwood Lakes (*Salmo agua-bonita*, Jordan). Trans. Amer. Fish. Soc. Vol. 64, pp. 259-265.

Davis, H. S.
1938. Instructions for conducting stream and lake surveys. Fisheries Cir. No. 26, U. S. Dept. of Commerce. 55 pp.

Gee, Merle A.
1942. Success of planting legal-sized trout in the Southwest. Trans. of Seventh N. Amer. Wildlife Conf. pp. 238-244.

Gordon, Seth
1950. California's fish and game program. Calif. Div. of Fish and Game. (In Press)

Hazzard, A. S.
1945. For better fishing. Mich. Conservationist, July-Oct.

Hazzard, Albert S., and David S. Shetter
1938. Results from experimental plantings of legal-sized brook trout (*Salvelinus fontinalis*) and rainbow trout (*Salmo irideus*). Trans. of Amer. Fish. Soc. Vol. 68, pp. 196-210.

Holloway, Ancil D., and Thomas K. Chamberlain
1942. Trout management and stocking results in the national forests of the Southern Appalachians. Trans. Seventh N. Amer. Wildlife Conf.

Hoover, Earl E., and M. S. Johnson
1937. Migration and depletion of stocked brook trout. Trans. Amer. Fish. Soc. Vol. 67, pp. 224-227.

Needham, P. R.
1937. Methods of measuring anglers' catches in inland waters. Copeia, No. 1, pp. 41-48.
1947. Survival of trout in streams. Trans. Amer. Fish. Soc. Vol. 77, pp. 26-31.

Needham, P. R., and E. P. Cliff
1938. Trout production in Fish Lake, Umpqua National Forest, 1937. Prog. Fish-Cult., No. 40, pp. 28-40.

Needham, Paul R., James W. Moffett and D. W. Slater
1945. Fluctuations in wild brown trout populations in Convict Creek, Calif. Jour. Wildl. Mgt. Vol. 9, No. 1, pp. 22-35.

Needham, P. R., and D. W. Slater
1943. Seasonal changes in growth, mortality and condition of rainbow trout following planting. Trans. Amer. Fish. Soc. Vol. 73, pp. 117-124.
1944. Survival of hatchery-reared brown and rainbow trout as affected by wild trout populatoins. Jour. Wildl. Mgt. Vol. 8, No. 1, pp. 22-36.

Needham, P. R., and Frank K. Sumner
1941. Fish management problems of high western lakes with returns from marked trout planted in upper Angora Lake, Calif. Trans. Amer, Fish. Soc. Vol. 71, pp. 249-269.

Nesbit, Robert A., and J. A. Kitson
1937. Some results of trout tagging in Massachusetts. Copeia, No. 3, pp. 168-172.

Randle, Allan C., and Frederick K. Cramer
1941. The Squaw Creek Test Stream. Calif. Fish & Game. Vol. 27, No. 3, July, 1941, pp. 172-184.
Schuck, Howard A.
1948. Survival of hatchery trout in streams and possible methods of improving the quality of hatchery trout. Prog. Fish-Cult. Vol. 10, No. 1, pp. 3-13.
Shetter, David S.
1944. Further results from spring and fall plantings of legal-sized, hatchery-reared trout in streams and lakes of Michigan. Trans. Amer. Fish. Soc. Vol. 74, pp. 35-58.
Shetter, David S., and Albert S. Hazzard
1940. Results from planting of marked trout of legal size in streams and lakes of Michigan. Trans. Amer. Fish. Soc. Vol. 70, pp. 446-468.
Smith, Lloyd L., Jr.
1940. The results of planting brook trout of legal length in the Salmon Trout River, Northern Michigan. Trans. Amer. Fish. Soc. Vol. 70, pp. 249-259.
Smith, Lloyd L., Jr., and Beatrice S. Smith
1943. Survival of seven-to-ten-inch planted trout in two Minnesota streams. Trans. Amer. Fish. Soc. Vol. 73, pp. 108-116.
Surber, Eugene W.
1940. Lost: 10,839 fingerling trout: An appraisal of the results of planting fingerling trout in St. Mary River, Virginia. Pro. Fish-Cult. No. 49, pp. 1-13.
Thorpe, Lyle M., H. John Rayner, and Dwight A. Webster
1944. Population depletion in brook, brown, and rainbow trout stocked in the Blackledge River, Connecticut, in 1942. Trans. Amer. Fish. Soc. Vol. 74, pp. 166-187.
Vestal, Elden H.
1943. Creel returns from hatchery trout in June Lake, Calif. Calif. Fish & Game. Vol. 29, No. 2, pp. 51-63.
Wales, J. H.
1946. Castle Lake trout investigation: first phase: interrelationships of four species. Calif. Fish & Game. Vol. 32, No. 3, pp. 109-143.
Williamson, Lyman O., and Edward Schneberger
1942. The results of planting legal-sized trout in the Deerskin River, Vilas County, Wisconsin. Trans. Amer. Fish. Soc. Vol. 72, pp. 92-96.

DISCUSSION

DR. COPE: Thank you. You have certainly given us something to think about. We shall have to curtail our discussion period a little bit so that we can get caught up.

MR. CLARENCE PAUTZKE (Washington): I cannot sit still and take the type of argument that you presented. For one thing, to provide fishing by Dame Nature for a few fishermen is all right, but to throw in half a million, you cannot provide it by allowing a 96 per cent mortality, as you expressed it by the results obtained from one high mountain stream of probably 4,000 or 5,000 altitude. Was that not right?

First, you have shunted off the only weapon with which we have got to operate, of actually putting something back into nature and using the natural reproduction with a high mortality. You have got to take a portion of the production of that stream and set it aside for holding your brood stock. You have got to drop the total number of catch of fish, so that you will have enough stock to rehabilitate, or continue to supply fish to that stream. In the situation of a stream with a tremendous amount of gradient, it is possible you will not hold too many fish. You classified all streams under that category. On streams in the high mountains that have beaver, 2- to 5-inch fish will make a lot more fishing than Dame Nature will ever be able to supply, and that is from actual returns on checked bags. Then, you are professing to say that only legal-sized fish are expensive. Anybody dealing with hatchery fish knows that most of the hatcheries are bumping against the ceiling from the amount of raw products that they can buy and feed through a hatchery. From a monetary standpoint, they have got to be able to utilize those smaller size and age groups, not at $150 to $200 a thousand fish, but at $4 to $5 a thousand.

You have not touched on the program of the possibility of rehabilitating lakes, one of the weapons that can be used in some of the lowland lakes. I quote from many, many experiences on 138 lakes that we have already rehabilitated. Take a lake like Spencer Lake, that has produced less than a thousand fish per year; that was 38 per cent catfish, 29 per cent perch and some bass and some trout. It was planted after being poisoned out the opening year. They took 70,000 half-pound trout on it and that was on fish that were put in at 1,500 to the pound on rainbow. In the planting of your stream, it is true that where you have low production of food, yes, if you have to push those small fish through an extremely critical winter, that you will not have the survival, but I do not deem it necessary to take and plant those fish so they are immediately taken by the rod; in other words, put and take immediately. On a series of tagged fish planted in the Cedar River in April 1949 those fish were taken throughout the stream system up into September. I would say that if the fish men would use some of the information that is available, that they can obtain a high degree of returns upon all age groups of fish, but I do not think it is right to simply say you took a certain size fish that did not make a return and therefore hatcheries are not beneficial.

DR. NEEDHAM: May I make one comment on that? On the rehabilitation of poisoned fish population by the installation of shelter or any of the other things you might do for habitat improvement, I go along 100 per cent. It should be done, no question about it. To get back to saying that nature cannot support the burden of angling. Of course it cannot under conditions of intensive angling, if it cannot let the brood stock survive. At Convict Creek we found survival of 30 brood females per year would be enough to reseed that stream at the intensity of the population as we found it.

The point I am getting at is this—I do not care which stream you are talking about. When you are talking about cold mountain torrents, we have ample evidence. It is on the books, it is in the papers of some 20 or 30 different men who have conducted this research and the evidence is there. Let us rely on Mother Nature for the bulk of the fish to be taken and if the cost becomes objectionable, in fact staggering, then I think probably we eventually will be paying a special fee for that fishing. Those who utilize those big, legal-size fish planted from the hatchery can just as well pay for them. Nowadays we are paying for them whether or not we go fishing for them. Why continue this utter waste of 2- and 4-inch fish when we know the mortality is practically zero? It does not make sense to me.

ECOLOGICAL EFFECTS OF WINTER CONDITIONS ON TROUT AND TROUT FOODS IN CONVICT CREEK, CALIFORNIA, 1951

JOHN A. MACIOLEK
U. S. Fish and Wildlife Service

AND

P. R. NEEDHAM
Department of Zoology
University of California, Berkeley, California

ABSTRACT

In 1951, winter studies were conducted at the Convict Creek Experiment Station of the U. S. Fish and Wildlife Service located at 7,200 feet elevation in the Sierra Nevada Mountains near Bishop, California. These were designed to extend knowledge of winter conditions in stream environments and to bring to light problems requiring further investigation at this season. Common stream survey methods were employed to procure and analyze data.

Snowfall was meager at Convict Creek in 1951, but freezing temperatures induced extensive ice formations. Surface ice immobilized screens and other objects protruding from the water, yet provided the trout with abundant shelter. Frazil and anchor ice had a more pronounced effect on stream life and water temperatures than surface ice. When subsurface ice was present, the water was at or very close to the freezing point, regardless of weather conditions or time of day. Anchor ice formed and dispersed in a daily cycle that caused wide fluctuations in stream flow. Minimum water flow at night often left secondary channels empty, while morning peak flows scoured the stream with ice fragments, washing loose debris and bottom fauna. Trout were active in the freezing water and fed regularly throughout the winter. Trout were caught on bait when the water was 32° F.

Large numbers of aquatic organisms were dislodged by fluctuating flows and became available as food for trout. Clear indications were obtained of high seasonal fluctuations in the abundance of bottom organisms. Adult stoneflies and dipterans emerged on warm days during the winter.

A comparison between the numbers of stream bottom organisms present, drift foods, and foods consumed by trout, gave a positive correlation. In cold weather, trout consumed large numbers of mayfly and stonefly nymphs, while dipterans predominated in trout stomachs over the entire winter. Rainbow and brown trout of similar lengths and stomach volumes differed in the number of organisms eaten by each in that rainbow trout ingested larger quantities of small organisms than did brown trout.

Wild trout suffered an initial mortality in early January that was caused by heavy subsurface ice which blocked stream flow into side-channels. Very few dead trout were found after this occurrence. The over-winter survival of marked trout approximated 50 percent in 1950-51.

Reprinted from Volume 81 (1951) TRANSACTIONS *of American Fisheries Society. 1952.*

Introduction

Studies of winter conditions in trout waters have been neglected in many areas. As was pointed out by Hubbs and Trautman (1935), inland fishery research has usually been limited to summer months because working conditions are better and there seldom are both living and laboratory facilities available and easily accessible for winter investigations. The Fish and Wildlife Service of the U. S. Department of the Interior has such facilities at its Convict Creek Experiment Station in Eastern California. In cooperation with the University of California it conducted a study of winter conditions over the period from November, 1950, through April, 1951. The main effort was directed toward discovering the effect on trout of low water temperatures, ice formation and dispersal, snow, and other ecological factors.

The principal species of fish in the area of Convict Creek where these studies were made are brown trout, *Salmo trutta* Linnaeus, and rainbow trout, *Salmo gairdneri* Richardson. Brown trout are by far the more abundant. Only rarely is an eastern brook trout, *Salvelinus fontinalis* (Mitchill), taken. Suckers and cyprinids are common in lower Convict Creek and in Lake Crowley, into which it flows some 3 miles below the Convict Creek Station.

The Study Area

The Convict Creek Station is located on the eastern escarpment of the Sierra Nevada Mountains in Mono County, California, at an elevation of 7,200 feet. Convict Creek rises in snow-fed lakes near the crest of the Sierras, plunges precipitously down a canyon, dropping 2,300 feet into Convict Lake. From here, the stream drops about 400 feet in 2 miles to the experimental area. Convict Creek below the lake flows rapidly through a boulder-strewn, tree-bordered canyon for about 1 mile, after which it enters flat meadow-like areas bordered on both sides by wide sagebrush flats. There the water course averages about 10 feet in width and has a bed of rubble, gravel, and sand. Natural spawning areas of fine gravel are found at frequent intervals. The pines, cottonwoods, birch, and alders that border the stream in the canyon are replaced by willows in the meadow. There is little aquatic vegetation except for small patches of *Ranunculus*. Under-cut banks, holes, submerged logs and debris provide excellent natural cover.

The experimental stream system now in use consists of four, one-quarter-mile channels. The full flow of the stream is divided in half, each half then flowing through two sections which are screened at their upper and lower ends. A flood control structure is provided above the area to divert excess flood waters around the four experimental stream sections. The winter studies described in this report were made principally within the areas encompassed by the Convict Creek Station, though some of the observations were made in adjacent waters both above and below the station area proper.

Winters at Convict Creek are characterized by heavy snowfalls, high winds, and low temperatures. Snow usually averages 2 to 4 feet deep on the level and wind-borne snow, blown from adjacent high ridges, often bridges the entire width of the creek.

The winter of 1950-51 was comparatively mild in that less than 2 feet of snow fell during the period of study, and low temperatures alternated with periods of mild weather. Nights were generally cold and clear while days were bright and windy. Only two periods of extreme cold weather occurred in 1951. These were severe enough to cause heavy ice formations in the stream and permitted observations of their effects on stream ecology.

Methods and Equipment

The techniques and equipment employed were those generally used in stream survey work. Stream bottom organisms were collected with the Surber square-foot sampler. This device, with a coarse screen fender, was used as a stationary net to capture stream drift organisms. It was staked to the bottom of the stream for 15-minute intervals at various times of day and under varying stream conditions.

Trout for stomach analyses were taken by seine, trap, and angling. Water flow records (Table 1) secured from the City of Los Angeles were supplemented by additional flow measurements taken with a White current meter. Continuous air and water temperatures were taken by

Table 1.—*Mean monthly discharge of Convict Creek from November, 1950, through April, 1951.*

Month	Stream flow cubic feet per second		
	Mean	Maximum[1]	Minimum[1]
November	18.9	44.3	6.5
December	23.0	35.1	13.7
January	10.6	13.7	1.3
February	10.4	13.9	9.2
March	8.3	10.8	7.2
April	11.2	15.4	7.7

[1]Refers to extreme daily means occurring within the month.

means of a Taylor recording thermometer ranging from 0°F. to 100°F. and graduated in 1° intervals. Temperatures taken from these charts (Table 2) were read to the nearest 0.5°F. Supplementary water-temperature measurements were made with a Foxborough resistance thermometer, the vernier of which was graduated in half degrees and interpolated to the nearest 0.1°F. Water temperatures reported here were taken with the resistance thermometer, unless otherwise noted.

TABLE 2.—*Mean monthly maximum and minimum air and water temperatures in Fahrenheit and mean times of occurrence at Convict Creek, California, January 1 through March 31, 1951.*[1]

Month	Air temperatures				Water temperatures					
	Monthly mean		Monthly mean		Monthly mean		Monthly mean		Minimum water temperatures[2]	
	Maximum	Time	Minimum	Time	Maximum	Time	Minimum	Time	Average length of period	Total hours
January	44.5	2:00 P.M.	16.3	4:15 A.M.	37.9	3:00 P.M.	32.8	5:45 A.M.	9:45 P.M.—1:30 P.M.	222
February	47.5	2:30 P.M.	18.1	4:00 A.M.	40.2	3:15 P.M.	32.9	5:30 A.M.	12:15 A.M.—11:15 A.M.	166
March	53.2	2:45 P.M.	19.9	3:30 A.M.	44.5	3:30 P.M.	32.8	5:30 A.M.	1:00 A.M.—10:00 A.M.	117

[1]Compiled from thermograph charts, Taylor recording thermometer
[2]Temperatures of 32° F. or lower.

Ice Formation in Stream

Three types of ice may appear in streams in boreal climates. Surface or sheet ice which forms over the surface of the water is most common. Frazil and anchor ice, two less known types, form within the water (subsurface). Frazil is an extremely soft, grey ice composed of fine spicules and may appear as feathery wisps undulating in the current, as clumps at the surface of the water, or as a stationary, slushy mass occupying the entire depth of the water. Anchor ice appears as a grey, translucent coat over immovable objects in the stream bed. It is composed of crystals larger than those of frazil, which makes it more granular and gives it some rigidity. Both subsurface ices, if free from particulate foreign matter, appear brilliantly white when removed to the atmosphere.

Surface ice formations grow from the edge toward the center of the stream until a complete layer is formed. It then thickens by crystallization on the underside as heat is transferred upward through the ice. In Convict Creek, sheet ice formed over the surface of slow pools and shelf-like along stream banks in riffle areas, reaching a thickness of 8 inches in some localities. Light accumulations of snow rendered it opaque.

Although surface ice may form when subsurface waters are well above freezing, subsurface ice never appears until the whole water mass reaches the freezing point. The time at which the stream reaches its lowest temperature coincides with the first appearance of subsurface ice. Barnes (1906) recorded the minimum temperature of the St. Lawrence River at —0.0068°C. (31.988°F.). In an experiment with a container of water that was agitated as it was cooled, Barnes also found the lowest water temperature was —0.014°C. (31.975°F.) at the time ice first appeared. Convict Creek waters showed a minimum temperature slightly below 32°F. Within minutes, particles of ice became abundant and the temperature increased slightly but retained a position between the minimum and 32°F. In Table 2, it will be noted that water temperatures of 32.0°F. or lower existed for a total of 222 hours in January, 166 hours in February, and 117 hours in March.

Both forms of subsurface ice may result from tiny, clear, colloidal particles which resemble ice but lack its true crystalline form. Colloidal discs formed quickly and extensively in Convict Creek on clear, cold nights when excessive terrestrial heat radiation lowered the stream temperature to freezing. They were secured from the stream by means of a cheesecloth strainer and measured up to 3 millimeters in diameter.

Frazil ice forms throughout the water as minute, irregular crystals, the extent of the formation being largely dependent upon the agitation of the water. Turbulence may be produced both by swift currents in steep riffles and by wave action from strong winds. Frazil ice was also formed from the crystalline growth of colloidal particles and from supercooled snow falling into water which was at or below the freezing point.

The volume of frazil formed on a cold windy day may be immense, for Barnes (1928) reports accumulations up to 80 feet in thickness beneath surface ice on the St. Lawrence River. Large quantities of frazil appeared in Convict Creek on only one day during this study.

Terrestrial radiation is commonly accepted as the cause of anchor ice formation. At Convict Creek anchor ice formed only at night and apparently never under an overcast sky or opaque layer of surface ice, since these tended to reflect the heat being radiated from the earth below. The cloud-like masses of anchor ice that formed nightly made up the bulk of the ice. Anchor ice was observed to form soon after the appearance of colloidal discs: first, on the rubble at the downstream ends of pools; second, on the rough substrate in riffles; and lastly, at the bottom of pools. The amount of this ice formed in any one night was determined by depth, turbulence, and rate of heat radiation from the water. Most of the colloidal particles, as well as any frazil crystals present, adhered to the coarse anchor ice, grew, and became part of that formation.

Effects of Stream Ice

The effects of ice formation on stream life are both beneficial and harmful (Hazzard, 1941). Needham (1938) notes that snow-bridges completely covering small streams afford insulation against both cold and predators. Later, Smith (1947), in similar work on Convict Creek, found that wind-drifted snow combined with stream ice blocked an experimental stream channel and caused a 4-hour cessation of flow and a consequent draining of water from the channel into the substrate.

Sheet and shelf ice offer excellent shelter to trout along otherwise open stretches of stream. Brown and rainbow trout in Convict Creek took advantage of the increased cover. They could usually be frightened from these retreats by breaking loose a section of shelf ice. Surface ice greatly impeded observations and recovery of trout. It also caused much disturbance to the stream banks and bottom when water surges broke it loose. At such times, large masses of ice with embedded twigs, leaves, and other vegetation were swept over shallow riffles in heaps of tumbling cakes.

Subsurface ice, being far more abundant than surface ice, had a much greater effect. Frazil caused extensive damage to Convict Creek on January 19. In the early morning hours, winds of extreme velocity (estimated at 80 miles per hour) blew in snow from higher elevations and so churned the creek surface that the water became filled with fibril slush. The flowing water was forced into small channels within the slush and flooded out of the main stream at every turn where the banks were low. Moving masses of soft ice carried off two foot-bridges and caused other damage. The stream was carefully inspected during and after the ice dispersed, but no evidence of harm to trout was found.

Anchor-ice formations on rocks at the bases of pools raised the effective height of the pool dams and impounded considerable quantities of water. Encrustations of ice blocked the flow of water into side-channels and turned screens into watertight dams. The result was a gradual decrease in volume of flow. Solar radiation at dawn halted further growth of anchor ice and soon the radiant heat loosened the weak bond between anchor ice and substrate. Clumps of anchor ice broke free, and moved downstream with the current. Impounded water was liberated as the ice breakup progressed and the increasing flow scoured the stream,

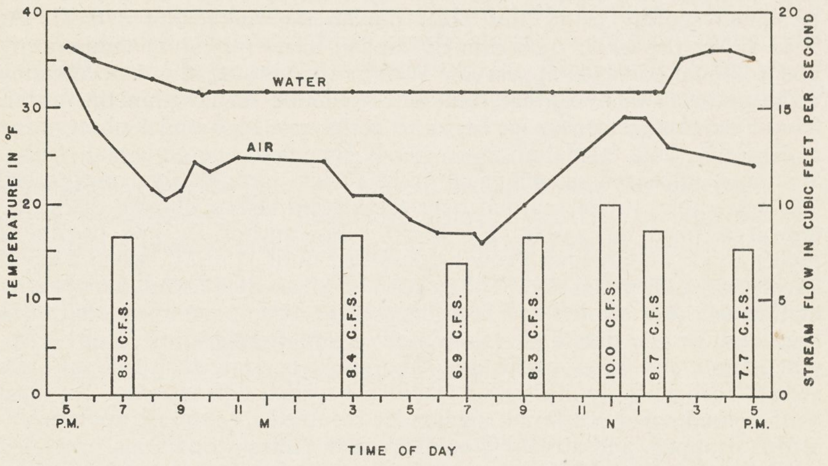


FIGURE 1.—Air and water temperatures and stream discharges recorded in Convict Creek, California, over a 24-hour period on February 25 and 26, 1951.

breaking loose additional quantities of ice and debris. At noon, February 23, a flow of 16.4 cubic feet per second was recorded in the area. The mean flow for this date, according to the discharge record, was 9.8 cubic feet per second. The flow, therefore, must have increased more than double between the early morning minimum and the measured maximum at noon. More typical were daily flows that varied by 4 cubic feet per second (Figure 1). The surge of water disturbed the stream bed enough to carry off many aquatic organisms. This dislodgement proved to be an advantage to trout by making riffle-dwelling insects such as mayflies, stoneflies, and caddiceflies readily available.

The presence of subsurface ice kept water temperatures at a 32°F. minimum (Table 2), but as soon as this ice was gone, water temperatures rose regardless of air temperatures or intensity of the sun. Reports of anchor ice lifting gravel, stones, and even large rocks are recorded by Barnes (1906), but these instances occurred in large waterways where suitable conditions enabled the ice to remain attached for several days and become quite thick. Convict Creek cleared daily and, upon one occasion, floating anchor ice had fine gravel imbedded in its base. Seining trout in ice-laden waters was impossible because a slight contact would dislodge the loose clinging ice and fill the net with jagged spicules.

Daily Temperature Cycle

A typical 24-hour period of winter stream and weather conditions is illustrated by data collected February 25 and 26, and presented in Figure 1. Air and water temperatures dropped steadily in the afternoon and evening of February 25. The air reached 32°F. at 6 P.M. and remained slightly below this point during the succeeding 2 days. At 9:45 P.M., the water momentarily dipped to its minimum temperature and colloidal particles appeared. Within 10 minutes, the concentration of these discs was so great that they could be seen within the water. Fine filaments of anchor ice began to form on a rock under observation at 10 P.M. This formation grew visibly for several seconds and, within a minute, appeared on many adjacent rocks. Growth then progressed less noticeably, to form a mat over the stream bed. Colloidal discs disappeared from the water. By 10:30 P.M., anchor ice had become 2 inches thick, and further growth continued until 11 P.M., when a cloud cover moved over the sky. The growth of anchor ice halted temporarily and stream flow, which had been decreasing by impoundment, began to rise slightly. A fine, light snow fell intermittently until 3:00 A.M., when the cloud layer broke up. The snow crystals that fell into the stream formed filmy masses of frazil that trailed downstream. As soon as the cloud cover scattered, anchor ice resumed its growth, air temperatures dropped, and stream flow decreased. These conditions prevailed until sunrise, when the anchor ice had reached a thickness of 7 inches.

Little change was observed between sunrise (6:45 A.M.) and 8:30 A.M., except a slight loosening of anchor ice from the stream bottom and a visible increase in stream flow. The real breakup of anchor ice commenced at 8:30 A.M., causing a rapid increase in volume of flow. At this time, many trout appeared in the stream to feed on the food being carried downstream. Stream flow leveled off shortly after noon. All anchor ice became free from the stream bed by 1:30 P.M. and stream flow then dropped noticeably. After floating clumps of subsurface ice disappeared at 1:50 P.M., the water temperature rose suddenly to 36°F. at 3:30 P.M. After this time trout ceased to feed and both temperatures and flows slowly decreased to 5:00 P.M., thus completing the 24-hour cycle.

Activity of Trout

It is generally assumed that trout are less active during the winter months than in the warmer seasons. Excluding migrations, this condition was found untrue, since trout in Convict Creek were quite active in spite of cold water temperatures. Most of the time, the fish remained under shelf ice, cutbanks, and among willow roots and brush. As the sun took effect upon subsurface ice, trout suddenly appeared in the open stream. Throughout the day, especially as temperatures rose, the fish could easily be observed. In late afternoon, trout seemed to disappear as the temperatures dropped. Very few trout were seen at night, although several fish kept in a live car were observed at all hours. These fish were far from sluggish at night in the freezing, ice-laden water. Frazil and anchor ice usually had to be cleared away to find the trout, but they deftly avoided capture by hand.

No device was installed to check migrant fish but a careful watch was kept at the screening points on the experimental sections. During fall months, brown trout fingerlings nearly always could be found in the enclosed water between the screens and the flashboards. One warm February day with the water at a monthly peak of 44°F. several fingerling brown trout were observed on the concrete apron of the lower screen structure attempting to enter the experimental sections. No such attempts were observed again until late March, at which time the water temperatures rose above 43°F. Two large brown trout tried to enter the sections in late January and early February during a warm spell of weather.

Some trout normally occupied small side channels during summer and fall. Observations indicate that these trout vacated the side channels in early January, frequented them occasionally on warm winter days, and returned from the main stream to reinhabit the smaller channels in late March.

Winter Food Supplies

Winter is the time of greatest abundance of immature aquatic insects, a matter of considerable importance to trout. Besides the usual forms of aquatic organisms common to Convict Creek, an abundance of aquatic oligochaetes [*Helodrilus tetraedrus* (Savigny)] appeared during the months of study. So numerous were these bristle-worms in certain areas that a handful of coarse sand from the stream bottom yielded a dozen individuals. They formed approximately 10 percent of drift and bottom foods available to trout in the winter of 1951.

The emergence of adult insects was a fairly common event throughout the winter, perhaps because the weather was mild in 1951. On December 29, a hatch of blackflies (Simuliidae) took place. Thereafter, on warm days in latter January, mid February, and most of March, when water temperature was 40°F. or more, some blackflies and many midges (Chironomidae) emerged. Adult stoneflies (genera *Nemoura* and *Capnia*) appeared abundantly in late January and sparingly during the remainder of the winter. Besides these aquatic forms, terrestrial dipterans and lepidopterans were found. Mayfly and microcaddis adults (Hydroptilidae) began emerging in late March.

Bottom Foods

Few quantitative riffle bottom samples have been taken under severe winter conditions. Needham (1938) reports a standing crop of 103 pounds per acre in the Merced River in California in February of 1933. Bottom samples taken from the same riffle in August produced an average of 85 pounds per acre. Both of these figures are based upon four samples. Convict Creek, from a series of five samples taken in February of 1942, indicated an average standing crop of 134 pounds per acre.

It is of interest to compare the amount of bottom foods found in winter with those obtained from summer samples in Convict Creek. Over the 5-year period from 1938 through 1942 inclusive, 225 bottom samples were taken in Convict Creek between May and September. Unpublished data indicate that the 5-year average was 109 pounds per acre and the average, annual summer amounts varied from a low of 68 pounds per acre in 1938 to a maximum of 197 pounds in 1942. While the five winter samples taken in 1942 produced an average of 134 pounds per acre and are far too few in number for any adequate comparison with summer food conditions, nevertheless it is evident that the 134 pounds per acre is well above the average of 109 pounds indicated for the five seasons covered. The reasons for greater abundance of bottom foods in winter must be that few aquatic insects emerge in winter and therefore the bulk of them are present in one stage or another.

A comparison of the food organisms found in 11 bottom samples taken in the winter of 1951 and the 5 samples secured in February, 1942, is presented in Table 3. Mayfly nymphs dominated the 1942 samples forming over 53 percent of the 1,865 animals collected, while in the 1951 series other groups were relatively more numerous. Caddicefly larvae, for instance, contributed over 29 percent. Midge larvae made up over 12 percent of the 1951 samples and 18.8 percent of the 1942 collections. Oligochaetes were much more abundant in 1951 when they totaled 139 or almost 12 percent. In 1942 only 79 of these organisms formed 4.2 percent.

Wide differences in both seasonal and yearly abundance of bottom food are indicated in the above figures. The average number of animals collected per square foot in the 1951 winter samples was 107; that for the five taken in February, 1942, was 373 or over three times as many. As was pointed out above, the 1942 summer series of samples indicated an average of 197 pounds per acre and evidently the winter abundance was reflected over the following summer when the measured crop increased from the winter average of 134 pounds to 197 pounds per acre.

The implications of these findings with respect to stocking policies are obvious. Evidently stream populations are highly unstable and subject to vicissitudes similar to those of land animals and plants. The use of arbitrary stocking tables will, we feel, become a thing of the past or they will have to be modified by the development and application of factors to reduce or increase the numbers of fish to be stocked in relation to variable seasonal or annual conditions and fishing pressure.

Drift Foods

A total of 130 organisms was collected in nine samples. As will be seen in Table 4, caddicefly larvae and dipterans occurred in equal numbers followed by mayfly nymphs, oligochaetes, beetles, and stonefly nymphs, respectively. In terms of weight, oligochaetes contributed over 55 percent, mayfly nymphs, 26.5 percent, with the other groups contributing relatively minor amounts.

Table 3.—*A comparison of the number and percentage of riffle bottom organisms from Convict Creek in 1942 and 1951 (11 samples, 1951; 5 samples, 1942).*

Group of organisms	January-March, 1951		February 9, 10, 1942	
	Number & stage[1]	Percentage	Number & stage[1]	Percentage
Ephemeroptera	258(n)	21.8	995(n)	53.4
Trichoptera	346(l) 1(p)	29.3	237(l) 1(p) 1(a)	12.8
Diptera	140(l) 2(p) 5(a)	12.4	351(l)	18.8
Coleoptera	151(l) 39(a)	16.0	162(l) 18(a)	9.7
Plecoptera	37(n) 1(a)	3.2	10(n)	0.5
Oligochaeta	139	11.7	79	4.2
Miscellaneous	67	5.6	11	0.6
Totals	1,186	....	1,865	....

[1]Abbreviations used: l—larvae, n—nymphs, p—pupae, and a—adult.

The greatest number of drifting foods was always found during periods of peak flow. On one occasion, a set made from 11:10 A.M. to 11:25 A.M. contained a large number of insects, while sets preceding and following it by 15 minutes, gave meager returns. The organisms captured in this manner (Table 4), as might be expected, are generally the smaller ones of weak attachment or poor swimming ability. It is conceivable that larger organisms return to the substrate quickly upon being dislodged, while smaller ones may be carried far in the current.

Trout were observed feeding only during and following peak flows. It was thought that, under these conditions, trout might feed only upon the drifting organisms. Data from bottom samples, drift samples, and trout stomachs taken during such periods are grouped for comparison in Table 5. Here it is evident that there was some correlation between availability and ingestion. Caddiceflies were dominant in the four bottom samples concerned, forming 28.3 percent by number, while this group totaled 41.7 percent of foods eaten by 18 trout and 28.5 percent of all drift foods available. Similarly, mayfly nymphs formed 19.4 percent, 23.8 percent, and 31.8 percent, respectively, of the number of bottom, drift, and ingested foods. Comparing these on a basis of weight (Table 5), little correlation is evident.

Stomach Examinations

A few trout were collected by seine, trap, and angling each week for stomach examinations. Analysis of these data shows a marked difference between the winter food habits of brown and rainbow trout (Table 6). Forty brown trout stomachs contained 578 organisms or 14.5 per fish, while 53 rainbow trout consumed 1,337 organisms or

Table 4.—*Number and weight of organisms taken in 9 drift net samples, Convict Creek, California, February 19 through March 8, 1951.*

Group of organisms	Number & life stage[1]	Percentage by number	Weight in grams[2]	Percentage by weight
Oligochaeta	14	10.7	.139	55.8
Coleoptera	3(l) 1(a)	3.1	.001	0.4
Diptera	29(l) 5(p) 3(a)	28.5	.020	8.1
Ephemeroptera	31(n)	23.8	.066	26.5
Plecoptera	3(n)	2.3	.006	2.4
Trichoptera	37(l)	28.5	.016	6.4
Miscellaneous	4	3.1	.001	0.4
Totals	130	....	.249	....

[1]Abbreviations: l—larvae, n—nymphs, p—pupae, a—adults.
[2]Weight from alcohol.

25.2 per fish. Yet, the mean stomach volume for all brown trout was 0.29 cubic centimeters, and that for all rainbow trout was 0.28 cubic centimeters. This difference in numbers of organisms consumed is accounted for by the greater percentage of larger organisms in brown trout stomachs. The rainbow trout ingested many small midge and blackfly larvae, while brown trout consumed proportionately more caddicefly larvae.

Over the whole winter period dipterans represented only 12.4 percent of total available bottom organisms (Table 3) but supplied the greatest percentage in numbers of food items eaten (Table 6), both by rainbow (54.9 percent) and brown trout (31.6 percent).

Further analysis indicates a difference in general winter feeding habits as compared to strictly cold water feeding. A comparison of foods ingested in ice-laden water (Table 5) with those taken during the entire winter, December 29 to March 22 (Table 6), denotes a greater cold water consumption of mayflies, stoneflies, and caddice-flies, with more flies (Diptera), beetles, and oligochaetes being ingested during the entire period of study.

A rainbow and a brown trout between 6 and 8 inches long each had two, eyed trout eggs in their stomachs (Tables 5 and 6). This was the only direct evidence of disturbance to spawning beds observed. These fish were taken during extremely cold weather when much anchor ice formed at night. The action of ice in disturbing spawning gravels may have freed these eggs in the current. Scarcity of trout eggs in the stomachs suggests that anchor ice in the winter of 1951 caused slight disturbance to naturally spawned brown trout eggs.

TABLE 5.—*Comparison of fish food organisms from 4 stream bottom samples, 9 drift net samples, and 18 trout stomachs,[1] Convict Creek, California, February 19 to March 8, 1951.*

Group of organisms	Percentage by number			Percentage by weight[2]		
	Bottom foods	Drift foods	Ingested foods	Bottom foods	Drift foods	Ingested foods
Trichoptera	28.3	28.5	41.7	12.2	6.4	58.1
Ephemeroptera	19.4	23.8	31.8	5.4	26.5	9.4
Diptera	14.0	28.5	17.2	8.7	8.1	10.2
Plecoptera	3.0	2.3	4.0	11.8	2.4	1.6
Oligochaeta	10.7	10.7	2.7	60.6	55.8	9.8
Coleoptera	22.0	3.1	1.3	1.2	0.4	1.5
Miscellaneous	2.6	3.1	1.3	0.1	0.4	9.4

[1]Stomachs from 9 brown and 9 rainbow trout.
[2]All weights from alcohol.

Observations and stomach examinations indicate that low water temperatures did not limit the feeding activity of trout in Convict Creek. In over 100 healthy specimens of trout taken, only one rainbow

TABLE 6.—*Organisms found in stomachs of 40 brown and 53 rainbow trout, Convict Creek, California, December 29 through March 22, 1951.[1]*

Group of organisms	Brown trout		Rainbow trout	
	Number[2]	Percentage by number	Number[2]	Percentage by number
Oligochaeta	27 17(l)	4.7	46 45(l)	3.4
Coleoptera	26(a) 143(l) 14(p)	7.4	7(a) 712(l) 12(p)	3.9
Diptera	26(a) 65(n)	31.6	10(a) 187(n)	54.9
Ephemeroptera	2(a) 14(n)	11.6	1(a) 8(n)	14.1
Plecoptera	2(a)	2.8	2(a)	0.8
Trichoptera	215(l)	37.2	288(l)	21.5
Miscellaneous	27	4.7	19	1.4
Total	578	....	1,337	....

[1]Brown trout size—range was 8.3 to 20.7 centimeters (total length), with a mean total length of 14.3 cm. Rainbow trout ranged in size from 8.0 to 31.7 centimeters and had a mean total length of 14.5 cm. Total length as used here means length from tip of snout to end of caudal rays.
[2]Abbreviations used: l—larvae, n—nymphs, p—pupae, a—adults.

and three brown trout had stomachs that contained only a trace of food or none at all. Trout were observed feeding at all water temperatures. On several occasions trout were taken by hook and line (using a single egg or an aquatic bristle worm) in ice-laden water at a temperature of 32°F. Surface feeding was observed whenever aerial insects were present and usually at a water temperature of 35°F. to 42°F. The regularity of trout feeding during periods of low water temperatures raised the question of digestive rates. Hess and Rainwater (1939) reported that brook trout digestion was almost at a standstill in 1.9°C. (35.4°F.) water. A superficial experiment was conducted at Convict Creek by the senior author, in which several trout were force-fed mayfly and stonefly nymphs, and aquatic oligochaetes, then returned to a live car in the creek. Examinations of the trout stomachs at various intervals indicate that at least 50 percent of the total food fed to each fish was digested in 14 hours at temperatures between 32°F. and 35°F.

Trout Mortality

Winter has long been suspected as the season of greatest trout mortality. Needham, Moffett, and Slater (1945) found that overwinter decrease in brown trout in Convict Creek averaged 60 percent over 4 years in uncontrolled stream sections. This loss was attributed to the severity of winter conditions, principally drifting snow and ice. Needham and Slater (1944) report the smothering of several hundred trout by the collapse of a snowbank into a rearing pond.

Because there was light snowfall in the winter of 1951 in the Convict Creek area, there was no opportunity to study the effects of this factor. A type of winter mortality occurred during early January in which trout of all sizes were victims of cold weather. On January 10, following 3 days of low temperatures, 63 trout were found stranded on damp rocks at the bottom of shallow pools in a flood control bypass. Heavy nightly subsurface ice formations at the flood control structure, combined with incomplete daily thawings, had progressively diminished the flow of water into the bypass. In the early morning hours of January 10, water had ceased to flow into the bypass and the fish were suffocated where the water drained into the porous substrate. Layers of surface ice insulated the fish from freezing. This type of mortality was not confined to the bypass. Several days later, after warm winds and sunshine had melted surface ice from the stream, other dead trout were observed in similar situations, some in natural side channels as far as 1½ miles above the Experiment Station. No other cause of mortality could be directly attributed to winter conditions in the present study. Predation was unimportant at Convict Creek, since no predatory birds or mammals were seen during the study nor were their tracks or signs found. A 24-inch female brown trout was found to have eaten another trout about 6 inches long.

Throughout the winter, very few trout seen or captured were in poor condition. However, dead and emaciated trout recovered within the experimental sections between November 7, 1950, and April 21, 1951, totaled 7 brown and 46 rainbow trout. Thin, weakened fish, carried downstream by the current, were retrieved dead or dying at the screen structures. The higher percentage of hatchery rainbow trout found is indicative of their greater susceptibility to winter emaciation than wild brown trout. This mortality is peculiar in that it never occurred in periods of freezing weather. Between January 1 and March 15, only 11 dead trout were picked up at the screens, and these appeared only in the warmest weather. Possibly this is the result of a lower metabolic rate in colder water.

If any line is to be drawn between advantageous and detrimental winter conditions, it must be one of degree. The winter experienced during this study is considered mild because of the lack of snow. Low air and water temperatures occurred (Table 2) but were probably shorter in duration than in winters having more severe climatic conditions. Generally, trout fared quite well, for ice conditions that caused a small initial winter mortality, later offered fish cover and food. It is probable that lower temperatures, more continuous cold weather, heavy snowfalls, or a combination of these would have a more drastic effect on fish and other stream life.

Operational Hazards of Experimental Sections

The year 1951 marked the first winter operation of the Convict Creek Station. The main purpose was to determine over-winter survival rates of wild and hatchery trout planted in experimental stream sections. It was found impossible to pass stream-borne ice and slush through the screens and, when the water temperature dropped to 32° F., ice formed in the screen meshes creating dams which forced the water to flow over or around water control structures and channels. Although it was observed that trout were reluctant to migrate any distance when water temperatures were below 42° F., it was nevertheless apparent that there existed abundant opportunity for escape of fish from the experimental sections during periods of overflow. Strong winds greatly increased the flow of Convict Creek by increasing out-flow from the lake 2 miles above the station, and also caused formations of heavy clumps of spray ice to form around the screen structures. Surface ice often froze screens solidly in the concrete slots of the flumes, making it impossible to remove them for cleaning. High winds frequently blew heavy quantities of leaves into the stream which plugged screens before they could be removed, and caused overflow around or over them.

In spite of these difficulties when the fish were recovered from the stream sections during the last week of April, 1951, approximately 50 percent of the marked trout stocked in November, 1950, had survived.

Acknowledgments

We wish to thank Reed S. Nielson, Chief of the California-Nevada Inland Fishery Investigations of the Fish and Wildlife Service, who provided many of the facilities and much good advice in the course of the field work, and Bobby D. Combs, Fishery Research Biologist, who gave much aid in the course of his duties as Supervisor of the Convict Creek Station. To Dr. R. L. Usinger of the Division of Entomology, University of California, we are indebted for aid in determining many of the aquatic insects and for his initial reading of the manuscript. The aquatic oligochaetes were determined by Dr. Henry W. Olson of Wilson Teachers College, Washington, D. C. Records of stream flows on Convict Creek were obtained from the City of Los Angeles, Department of Water and Power.

Literature Cited

Barnes, Howard T.
1906. Ice formations, with special reference to anchor ice and frazil. John Wiley and Sons, New York. 260 pp.

Barnes, Howard T.
1928. Ice engineering. Renouf Pub. Co., Montreal. 364 pp.

Hazzard, Albert S.
1941. The effects of snow and ice on fish life. Proceedings Central Snow Conference, Vol. 1, pp. 90-94.

Hess, A. D., and J. H. Rainwater
1939. A method of measuring the food preference of trout. Copeia, 1939, No. 3, pp. 154-157.

Hubbs, C. L., and Milton B. Trautman
1935. The need for investigating fish conditions in winter. Trans. Am. Fish. Soc., Vol. 65 (1935), pp. 51-56.

Needham, Paul R.
1938. Trout streams. Comstock Pub. Co., New York, 233 pp.

Needham, P. R., and D. W. Slater
1944. Survival of hatchery-reared brown and rainbow trout as affected by wild trout populations. Jour. Wildlife Man., Vol. 8, No. 1, pp. 22-36.

Needham, P. R., J. W. Moffett, and D. W. Slater
1945. Fluctuations in wild brown trout populations in Convict Creek, California. Jour. Wildlife Man., Vol. 9, No. 1, pp. 9-25.

Smith, O. R.
1947. Returns from natural spawning of cutthroat trout and eastern brook trout. Trans. Am. Fish. Soc., Vol. 74 (1944), pp. 281-296.

FISHERY RESEARCH AT MID-CENTURY

W. J. K. Harkness

Division of Fish and Game, Department of Lands and Forests
Toronto, Ontario

Justin W. Leonard

Michigan Department of Conservation
Lansing, Michigan

and

Paul R. Needham

Department of Zoology, University of California
Berkeley, California

Reprinted from Volume 83 (1953), Transactions of the American Fisheries Society.
Published 1954. Printed in U.S.A.

FISHERY RESEARCH AT MID-CENTURY [1]

W. J. K. Harkness

Division of Fish and Game, Department of Lands and Forests Toronto, Ontario

Justin W. Leonard

Michigan Department of Conservation Lansing, Michigan

AND

Paul R. Needham

Department of Zoology, University of California Berkeley, California

Abstract

In North America fishery research is approached by almost as many administrative avenues as there are agencies engaged in it. Between these agencies differences exist in needs, plans, staff organization, methods of enlisting public support, and in the application of research findings. This situation is desirable. In the comparative infancy of fishery science any tendency toward development of stereotyped doctrine should be deplored. Originality and eclecticism should be encouraged, both in training institutions and in research and administrative bodies. An objective review of apparent successes and failures to date, however, may prove of value in illuminating pitfalls and in pointing out procedures which have resulted in progress. From this review profitable methods and promising areas for future activity may be inferred by the reader.

Fishery research in North America, particularly on inland waters and with the objective of sustained or improved production of game and food fishes, came into being gradually. Based on the early work of naturalists, ichthyologists and limnologists and on the arts and crafts of the fish culturist, fishery research can hardly be said to have had a definite time or place of origin. By the end of World War I, however, when the eight-hour day, wide ownership of automobiles, and a rapidly growing system of highways resulted in an explosive increase in angling pressures, there arose a general demand for a scientific approach to the problems these pressures created. The few existing research programs were expanded and new ones arose in many places, their character determined largely by the

1 The authors were invited to present papers at a symposium on the organization, popularization and application of fishery research. Discovering that their prepared papers contained much duplication of ideas and material, they abandoned their manuscripts and conducted the symposium as a round-table discussion followed by audience participation. In this joint paper they summarize their individual and collective views.

knowledge, judgment and imagination of their creators. It is not surprising, therefore, that in the past three decades almost as many types of organizational plans for fishery research have arisen as there are agencies involved.

Whether or not we have progressed far enough and gained enough experience to permit formulation of dogmatic principles for planning, staffing, directing and selling a fishery research program seems doubtful. A body of trial and error experience has accumulated, however, and an appraisal of some of these approaches may be profitable.

Because of the nature of its support, fishery research has always been denied the security of personnel and programs widely enjoyed in other research fields. This situation is particularly true of investigations in the sport fisheries which, being almost invariably in public waters, are administered by and for the public through governmental agencies established for the purpose. Experience has shown that the license-buying public is prone, again unlike other research fields, to peer constantly over the shoulders of its fishery researchers, and that it does not hesitate to urge its own often emotional ideas in preference to the objective findings of trained scientists. For this reason fishery research cannot be planned, or its results implemented by management, without operation of a continuous and concurrent program of public education to insure understanding of methods, aims and objectives. If understanding is inadequate the program will falter. If understanding is lost the program may be discarded *in toto* and the baby thrown out with the bath water.

A host of prickly questions must be answered by the administrator of a research program before a wheel is turned. Will he undertake fundamental or applied research (if he is able to distinguish between these as separate approaches)? Will he recruit a sizeable group of mediocre workers at low salaries, with incident rapid turnover, or engage a smaller staff of outstanding men at salaries adequate to insure their retention? Is his working budget reasonably predictable, or is it subject to annual feast-or-famine whims of legislators? Will the men who conduct research be charged also with its translation into management? Should he spread his funds and personnel thin and attempt to cover a wide range of needs, or try to concentrate on bringing to fruition a few studies at a time while neglecting others? Can he protect his staff from political harassment?

An examination of the record shows that these questions have been answered in almost as many ways as places. And evidence of present soul-searching exists in almost every quarter, indicating that few administrators feel they have found the true and unmistakable pathway to salvation.

As Kipling's poem runs,

> "There are nine-and-sixty ways of composing tribal lays,
> And every single one of them is right."

Certainly there is no single "right" way to organize and operate a fishery research program. Any system that works is right, even though it might be utterly wrong in other hands or another location.

At the outset, there is the question of whether or not a public conservation agency should employ only management technicians and "farm out" its research problems to colleges and universities. This view appears to be most popular with department heads and deans of colleges and universities. In some instances the plan has seemed to be workable. Among its advantages are the freedom from outside pressures and from diversion to trouble-shooting assignments enjoyed by academic workers; the ready access of such workers to adequate library facilities, and the availability of other members of the academic community as consultants; and complete freedom of the researcher to publish findings without regard for effect on any agency's "policy." There are many examples, however, to support the belief that research done by an agency's own personnel will meet with more rapid acceptance by its other employees, and be more quickly incorporated in management than will new ideas which originate with another institution.

The line between so-called basic and applied research is hard to discern, if it exists at all. It is almost equally difficult to draw a line between research and its application in management. Seldom can research findings be applied with confidence until they have been tested by a pilot-plant run—and the pilot plant often may embrace an entire state or province. A large, well supported organization may be able to afford a modest sized ivory tower for fundamental research, a separate contingent to take care of routine inventory, survey and trouble-shooting, and a trained group of fishery managers to translate research results into action. Most agencies have found it necessary to ask their trained men to serve concurrently as researchers, managers, and public relations representatives, and it is a testimony to the energy and ability of these triple-threat men that they have contributed importantly to the advancement of our field.

The role of the fishery biologist will vary widely, depending upon his employer's needs. If he has the responsibility of organizing a research project he immediately becomes something of an administrator—and there are those who feel this is almost like having the chairman of the board also serving as head of the union local.

Actually, only the most starry-eyed of biologists can indulge in the luxury of ignoring administrative problems. He must make his own case for funds and facilities, plan his program within limits of the possible, and constantly scrutinize his plan with stern conscience to be sure he is assigning priorities on the basis of reasoned need rather than personal predilection. No matter how much latitude is allowed him by his administrative superiors, he will find it advantageous to keep them apprised of the reasons why he adopted the current project, why it seems more urgent than other desirable projects, and how it fits into the picture of over-all research needs. If he is thorough and foresighted in these considerations the chances are infinitely better that his project will emerge unscathed and unmutilated by the various axe-wielding officials through whose hands it must pass.

Without question, the prosecution of the project, once it has received the green light, should be up to the biologist, without administrative interference. That is the job for which his professional training qualified him, the job he was hired to do. How he does it, how he elects to use the personnel and facilities at his disposal, is up to him. If he can do the job alone, the problem is simple. If he has assistants it is up to him to break the project down into chunks that an assistant can handle. If the training and experience of these assistants is of subprofessional level he will have to supervise their individual efforts in considerable detail. If they are competent professionals he will be wasting time if he concerns himself with detail. He will need all his time and energy to assimilate and evaluate the information they supply to him.

A good research program depends about equally on opportunity, facilities, competent personnel, and funds in reasonably predictable amount. Predictability is more important, actually, than quantity, for only when plans can be laid for several consecutive years can the research chief avoid the evils of "quickie" research. Probably there is not a man in the business who would not prefer a budget of fifty thousand dollars per year for ten years to one half a million this year and no assurance for the years to come. One of the most wasteful features of government-supported fishery research, state or federal, is alternation of feast-or-famine appropriations which lead to a build-up of staff and facilities during fat years, only to see the staff dispersed and the facilities deteriorating from disuse during the lean. Ambitious research programs conceived and initiated in a flush period and left stranded a year or two later by drastic budget cuts leave biologist and administrator alike with half-truths and vague trends, and may be worse than no research at all from the management standpoint.

No research program can be successful unless its results are incorporated in management. Vital information loses its value if it lies ignored in the files. Research results must be translated into management by administrative decision. And only the boldest administrator will depart significantly from past procedure unless he feels assured of public support.

Education—making research findings available to the public in assimilable form—is essential to management progress. Experience repeatedly has shown that it is foolhardy to undertake any marked changes in a fish management program, no matter how sound the basis for the changes, unless the public understands the reasons. Even then old ideas die slowly, and a constant stream of information through all available publicity media may be required to win support for programs based on adequate facts. A prime example is the persistence of the artificial propagation of many species of fishes in the face of literally scores of experimental demonstrations of its lack of value.

Who is to accept responsibility for education of the public in the implications of new facts established by research? Many methods have been tried, none wholly successful. The researcher himself tends to be overcautious in releasing information, and too often cloaks his findings in obscure, dull, or just plain sloppy writing. The professional publicist can write copy people will read, but often has trouble finding out, from the researcher, just what the ideas are that he is supposed to get across.

Understandably, the most effective educational jobs have been done by the occasional biologist willing to learn how to write, and by the growing number of outdoor writers who have learned to read and comprehend technical language and reports.

Experience has shown that both administrator and general public must be kept constantly abreast of research progress. They cannot be expected to wait for the final report. On the other hand, if an account has been made of each step of research progress and its probable significance, both administrator and public stand a good chance of being ready to act without additional selling, once the investigation is completed.

In such a young and rapidly growing field as fishery research the question of what constitutes desirable professional training is constantly in the minds of employers and teachers alike. There seems to be rather general agreement that we have not yet accumulated enough "established doctrine" to warrant outlining a regular four-year college course in Fishery Biology, as is done in the older fields of Forestry or Economic Entomology, for example. For some time to come, courses of study providing a broad background in fundamental biological and physical science, and in the humanities, would seem to give a student his best undergraduate preparation, with instruction in specific fishery procedures and techniques reserved for postgraduate study and on-the-job training.

The type of practical training sometimes referred to as an "internship" is growing in favor with many administrators. Agencies which can offer summer work or part-time employment to fishery students serve both their own needs and those of the student. Agency-supported graduate assistantships have, historically, produced some of the most useful concepts and tools of our current management practice.

In summary, it would seem that future success of fishery research is contingent upon recognition, by all concerned, of the following admittedly over-simplified points:

1. Research work should be insulated from routine, "trouble-shooting," management investigations. Whether or not the two fields of activity should be wholly separated administratively is doubtful, since mutual understanding of problems by research and management personnel is most essential.
2. Administrators must realize that adequate time will be required to produce adequate research results, and do all they can to insure against the dropping of projects prior to completion.
3. The research program must be directed at top priority problems, and the aim must be accurate.
4. The public must be kept constantly informed of research progress and results, in comprehensible terms.
5. Maintenance of high standards of training and practice are bound to yield practical results in increasing quantity, and lead to public acceptance of fishery science as a recognized and useful profession.

Reprinted from
THE JOURNAL OF WILDLIFE MANAGEMENT
Vol. 17, No. 1, January, 1953

Freshwater Fishery Biology. By Karl F. Lagler. Wm. C. Brown Company, Dubuque, Iowa. V-X: 360 pp. Appendix A-D. Sept. 15, 1952. $5.75.

This book is a natural successor to Dr. Lagler's "Studies in Freshwater Fishery Biology", published in 1949. While the new book contains much of the material that appeared in the earlier publication, the present volume is much more complete and workmanlike. Further, it is much more usable since it is published in an attractive case in regular book form which should stand up under hard usage by students.

A glance at the Table of Contents indicates there are 25 chapters, totaling 301 pages with the remaining 59 pages being devoted to appendices. The separate chapters cover the usual concerns of fishery biologists and bring together within the pages of a single book much of the material used in fishery management techniques today. Titles of the chapters are: I, Natural History and Ecology; II, Freshwater Fishes of North America, North of Mexico; III, Identification of Fishes and Other Aquatic Organisms; IV, The Literature of Fish and Fisheries; V, Fish Anatomy; VI, Fish Embryology; VII, Life History Stages Following Hatching; VIII, Food Habits; IX, Age and Growth; X, Age and Growth (Continued); XI, Length-Weight Relationship and Condition; XII, Fish Populations; XIII, Yield Analysis; XIV, Fish Pathology; XV, Pollution; XVI, Laws; XVII, Fish Culture; XVIII, Fishery Survey of Lakes, Ponds, and Impoundments; XIX, Fishery Surveys of Lakes, Ponds, and Impoundments (Continued); XX, Improvement of Lakes, Ponds, and Impoundments; XXI, Stream Surveys; XXII, Stream Improvement; XXIII, Creation of New Fishing Waters; XXIV, Freshwater Commercial Fisheries; XXV, Freshwater Recreational Fisheries.

In Chapter II, pages 21 to 36 inclusive cover a table entitled, "Checklist and Economic Classification of Common and Representative Freshwater Fishes of North America, North of Mexico." The economic classifications are based on the following categories: Sport, Commercial, Fine Food, Coarse Food, Forage, or Other. It seems to this reviewer that these 15 pages could have been better devoted to other matters or the material should have been condensed materially. The format used by the printer in setting up the table wastes much space. Another criticism of this table is that not all western fishes are listed which might well have been mentioned such as the common western minnows in the genera *Siphateles* and *Hesperoleucus*. In addition several important suckers and minnows present in the Lahontan Basin in enormous numbers could have been included.

The splittail, *Pogonichthys macrolepidotus*, is listed as being both commercial and coarse food. So far as this writer is aware, the splittail is not caught and sold commercially nowadays in California. The edible qualities of many fishes are often determined more by the method of preparation than the nature of the flesh. From the standpoint of Pacific and Lahontan Basin fishes, the table could have been greatly improved.

In Chapter XXI, "Stream Surveys," he has followed the late Dr. G. C. Embody to a considerable extent. On p. 268, Embody's trout stocking table for streams is given almost in the same form as it was first published in 1927. The pool grades (shelter) and food grades upon which the numbers of trout to be stocked in relation to stream width are practically identical with Embody's. It is surprising that after some 25 years of experimental trout planting and survival studies by many workers, Dr. Embody's table is still presented today in its original form. Embody himself said in his 1927 paper that, "These values (those presented in his stocking table) are tentative and subject to revision as further investigations reveal the true status of the factors concerned." We know now that bottom foods may fluctuate widely from year to year in abundance; that survival rates of small trout are on the whole negligible; that survival is better in lakes, and highest with 6–10 inch fish planted during the fishing season; that flood and drought may drastically modify basic stream conditions from year to year and season to season. Work on bottom foods in western streams has indicated enormous amounts present in some streams such as the Klamath and Rogue on the coast or the Owens and the Truckee rivers draining eastward from the Sierra Nevada Mountains. The food grades of 1, 2 and 3 are simply inadequate for application on a national scale and the writer would have liked to have seen a more critical review of the whole stocking problem than is given by Dr. Lagler. In fairness it should be stated that Lagler says that, "Stocking is no longer regarded as the principal means for maintaining and improving fishing . . ." and again that it, "has been shown at times to be unnecessary, wasteful, and even harmful", (p. 178). But a broad, critical approach to the problem, well documented, is lacking. If Dr. Embody were alive today he would, I am sure, have given us revised tables, well grounded on more recent studies.

The book on p. 258, cites Welch, 1948, for the Surber stream bottom food sampler but the first description of this net was published by Eugene Surber in 1937 and thus the reference should have been to Surber, not to Welch.

A number of the chapters are quite brief; in fact too brief to afford much real substance to the reader. The discussion of "Fish Culture" given in Chapter XVII is superficial and so highly condensed as to detract rather than add to the book. Similarly, Chapter XVI, "Laws," covers precisely two and one-half pages and might better have been omitted entirely.

Appendix A gives 36 halftone figures of scales of common families of American fresh-water fishes. These are, for the most part, clean, clear and well printed. Also included in the Appendix are blank forms for use in fishery surveys, abbreviations for words used in the names of technical journals and periodic publications, a table on fish diseases and, lastly, temperature conversion tables from centigrade to Fahrenheit, inches to millimeters, eighths of an inch to millimeters, decimal equivalents, and ounces to grams.

The book is essentially concerned with techniques and methods rather than life histories and habits of any given fish or group of fishes. It is a "what to do" and "how to do it" book. For instance, in the index following the name, "brook trout" four page numbers are listed. Two of these refer to figures, one covering its anatomy (Fig. 9), and the other figures a scale (Fig. 142). The other two page numbers refer to two brief references to brook trout, one where the copepod parasite, *Salmincola edwardsii*, is noted as being specific for brook trout (p. 156) and the other where the use of brook, brown or rainbow trout for stocking small ponds is considered (p. 273). This instance is cited merely to indicate the scarcity of life history or ecological materials in the book.

One of the strongest aspects of Dr. Lagler's book is the fact that he gives an excellent series of references at the conclusion of each chapter. While lack of space obviously prevented inclusion of many desirable items, nevertheless, the author has done an excellent job of selecting the references given.

The book is well illustrated with both zinc cuts and halftones. Some of his best pictures are concerned with standard field equipment used by fisheries biologists, including such items as nets, chemical equipment, dredges, current meter and scale projection apparatus.

As an introductory text for beginning students, the book will prove to be of great value in their training programs and at the same time provide a ready source of reference and techniques to be used as they are required.
—Paul R. Needham.

Review

Reprinted from
THE JOURNAL OF WILDLIFE MANAGEMENT
Vol. 18, No. 2, April, 1954

Methods and Principles of Systematic Zoology. By Ernst Mayr, E. Gorton Linsley, Robert L. Usinger. McGraw-Hill, New York and London. x+328 pp., 45 Figs., 15 Tables. $6.00. 1953.

At long last here is a textbook that is going to become just as necessary for ecologists and zoologists concerned with taxonomic problems as Mayr's "Systematics and the Origin of Species" (1942) or Dobzhansky's, "Genetics and the Origin of Species" (1951). Ferris' "Principles of Systematic Entomology" (1928) provided a tool for budding entomologists and likewise had widespread use by taxonomists in allied fields. The present text, however, is much more broadly conceived, covering Taxonomic Categories and Concepts (Part I), Taxonomic Procedure (Part II), and Zoological Nomenclature (Part III). Where Mayr, Dobzhansky, and Ferris are less concerned with the broader outlines of taxonomic problems and more with their own disciplines in relation to speciation problems, the Mayr, Linsley, Usinger text is broad in scope, beautifully written in the main, and in most ways represents a complete and detailed formulation of taxonomic history, principles and procedures. It could have included much more on such items as quantitative methods, the concept of ecological species or races and evolution, but evidently a desire by the authors to keep the book to a reasonable size and to deal in facts rather than philosophy forced omission of these broader problems. The discussion of each item is brief and to the point and usually well supported by citation of numerous examples. The text contains evidence of much careful, thoughtful editing chapter by chapter and certain unevenness in the text doubtless resulted from the triumvirate nature of the authorship.

Part I includes three chapters: 1. Taxonomy, its History and Functions; 2. The Species and the Infraspecific Categories; 3. Classification and the Higher Categories. Part II includes six chapters bearing the following titles: 4. Collecting and Collections; 5. Identification and Taxonomic Discrimination; 6. Taxonomic Characters; 7. Quantitative Methods and Analysis; 8. Presentation of Findings; 9. Preparation of Taxonomic Papers. Part III covers eight chapters as follows: 10. Historical and Philosophical Basis of Nomenclature; 11. The Principle of Priority; 12. The Type Method and Its Significance; 13. Specific and Infraspecific Names; 14. Generic Names; 15. Family Names; 16. Names of Orders, Classes and Phyla; 17. Ethics in Taxonomy.

There is a separate bibliography for each chapter at the end of the book. To this reviewer at least, this makes for cumbersome general use unless one follows the references directly from the text. One composite bibliography for the entire book would have saved duplication of references and increased its general usefulness.

A glossary of taxonomic terms used is one of the most useful features. These, arranged in alphabetic order, are brief definitions of most terms commonly used in taxonomic work. This is quite complete with omission of only a few terms such as biotope and biocoenosis, though both biota and biotype are listed.

A feature that especially appeals to me because of its great value for beginning students in taxonomy is a "Discrimination Grid" presented on page 79 in Chapter 5. In this three-column table, three sets of questions are listed to aid the student in determining whether two given collections or samples are intrapopulation variants, subspecies or species. These are reproductive isolation, morphological differences and geographical relationships. The grid is suggestive only and its clear-cut divisions would not apply to some animal groups such as the Genus *Salmo* since the factors of reproductive isolation and geographic distribution are impossible to define in many instances. Nonetheless, this and many other extremely useful features make it certain that this book is likely to become a standard in its field for many years and its influence will be profound.
—PAUL R. NEEDHAM.

trout family, Salmonidae, originated in the cold waters of the Northern Hemisphere, that they were circumpolar in their original distribution, and that they could have made it into more southerly streams only by migration from the north, moving southward as steelhead or sea-run trout from stream to stream in the ocean when it was cooled by glacial run-off during past ice ages. With the retreat of glaciers northward and consequent warming of the ocean and lower stream courses in a semi-tropical region, the fish became land-locked in the stream areas that remained sufficiently cold for their continued survival. Any that attempted to migrate to the ocean would have been eliminated by excessive water temperatures. Thus we now find the non-migratory offspring of early sea-run stocks in a series of closely related, relict groups of trout isolated in the middle and upper courses of the streams draining into the Pacific in Mexico from the Sierra Madre Occidental.

Desert barriers and warm ocean areas would nowadays prevent any movement of trout from the Río Santo Domingo, for instance, around the tip of the Baja California peninsula (Cape San Lucas) into the streams of the west coast of Mexico or into the Colorado. The Colorado River cutthroat *(Salmo clarkii pleuriticus)* evidently gained access to the headwater tributaries of the Colorado by stream capture from the east slope, i.e., erosion cutting back and taking over tributaries that normally would drain eastward.

The theory of migration southward during glacial periods is further bolstered by the fact that in Asia, on the island of Formosa, is an isolated, relict Pacific salmon, *Oncorhynchus formosanum,* far south of the salmons' main range on an island cut by the Tropic of Cancer. It is quite possible that, like the trout of Mexico, this fish was able to move far south of its normal range during glacial periods and since has become effectively separated from its parental stocks by climatic and geographic barriers. Another significant point that makes me believe the trout of Mexico have been there thousands of years, is that in many instances we collected them above high falls which would obviously be impassable to trout moving upstream nowadays. Thus they must have migrated upstream before geological uplifts or erosive effects occurred that would have prevented access to upstream areas.

"In every failure there is some success." We introduced Nelson's trout twice and lost them each time. But trout from the mainland of Mexico offer even more exciting prospects for gaining a hardier, non-migratory rainbow. Maybe when we brought out those 50 yearlings in 1936, a new era was started when trout will be freely exchanged between the sister Republics to the mutual benefit of each.

Reprinted from Nov. 1956
A.I.B.S. Bulletin
Amer. Institute of Biological Sciences

The Sagehen Creek Experimental Wildlife and Fisheries Project

PAUL R. NEEDHAM, *University of California*

RESEARCH on wildlife and fisheries problems must be done largely in the field. Macro-habitat conditions at least, cannot be duplicated in the laboratory. Investigators in these areas of study long ago recognized the need for field facilities of either a permanent or temporary nature. Trailers, buses and portable cabins have often been used for short term studies. Stations like the Hunt Creek Fisheries Experiment Station operated by the Institute for Fisheries Research of the Michigan Conservation Department at Lewiston, Michigan, or the Convict Creek Experimental Station near Bishop, California, are usually larger, more permanent, and offer more complete facilities for long-term research. In areas of severe climate at least, research personnel doing year-round work, cannot nowadays be expected to live in tents pitched in the open.

44 inches but in the exceptionally heavy winter of 1951-52, the pack was 110 inches. An additional point in favor of the Sagehen site was the fact that this basin is in excellent shape with respect to soils, timber and general ecological conditions and offers many favorable opportunities for research on wildlife, fishery, and other biological problems. The area is entirely forested except for a few meadows along the stream. The dominant trees consist of Jeffery Pine, white and red fir, with much lodgepole in the wetter areas.

Sagehen Creek is fed by springs at its head and snow melt. It fluctuates from around 50 cubic feet per second in the spring snow melting period, to about 2.0 c.f.s. in September. Being small, the stream lends itself well to pumping and draining techniques used in sampling fish populations and for the operation of two-way fish traps.

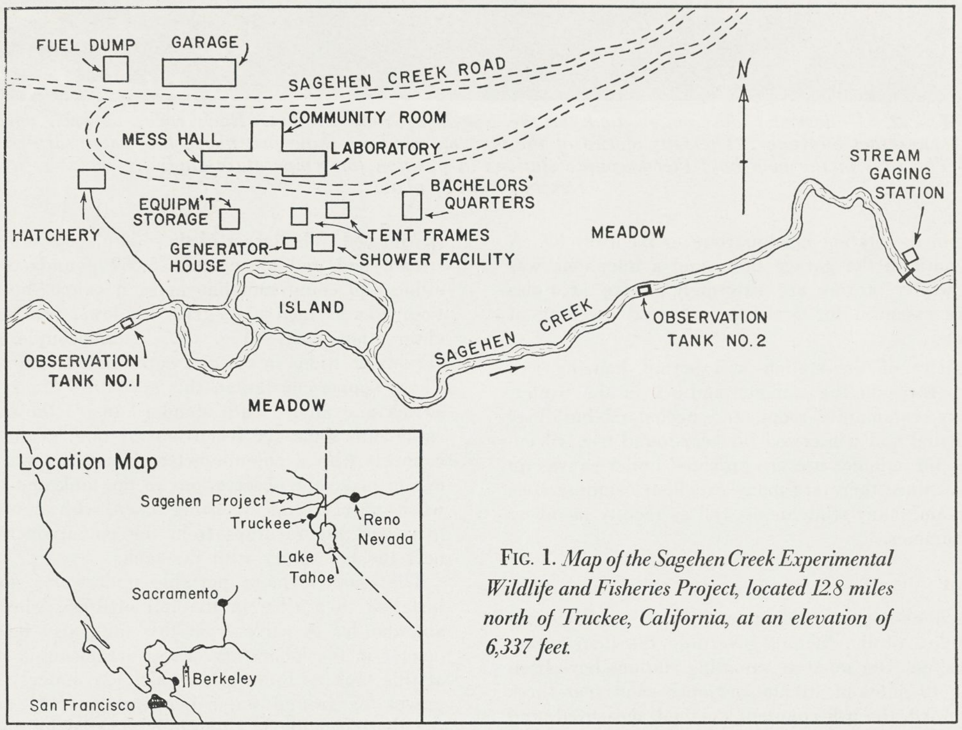


FIG. 1. *Map of the Sagehen Creek Experimental Wildlife and Fisheries Project, located 12.8 miles north of Truckee, California, at an elevation of 6,337 feet.*

The University of California administration recognizing the need for a high mountain field research center for use of faculty, graduate students and teaching in the fields of wildlife and fisheries, in 1951 authorized construction and research to be started at what is now called the "Sagehen Creek Project".

The site finally selected for the station is located in the Tahoe National Forest on upper Sagehen Creek, 12.8 miles north of Truckee, California (Fig. 1) at an elevation of 6,337 feet. Since the land on which the project is located was entirely in the ownership of the U. S. Forest Service, a Cooperative Agreement was drawn up which permits the use of about 112 acres of land and 1.25 miles of stream for an indefinite period of years. The selection of Sagehen Creek came only after an extensive reconnaissance of a large part of the various drainages of the state in 1950. The necessary prerequisites of a fairly small, controllable stream in an area of normal public use and vulnerability to severe winter conditions were found there. The average annual snow pack is about

Facilities

Construction at Sagehen was started in June of 1951. Through the summer of 1955, the following facilities had been completed: two tent frames, mess building, community room, workshop, laboratory with work space for eight students, electric generator house, fuel storage building, aquarium-hatchery building, garage, bachelor's quarters and a sanitary facility for summer use only. A darkroom is available in the garage. A 44° F. spring flowing 40 gallons per minute, supplies water by gravity to the Project for research and domestic uses. A phone line was constructed in 1953 from Hobart Mills into the project headquarters, a distance of 5.8 miles. This is essential for protection of personnel, especially in winter when the roads are closed. As further protection for personnel at this season, a second garage was built in 1955 at the junction of the Sagehen Road with State Route 89. The latter road is kept open in the winter while the Sagehen Road is not and a small Sno-Cat was purchased for winter snow travel over the

Fig. 2. *Underwater observation tank at the Sagehen Creek Project. Rock racks at each end counteract buoyancy. The tops of two of the viewing windows show just above the water surface. The rods in the pool hold thermocouple stations in position for temperature studies. Access is by ramp at right of photo.*

two mile section from the station headquarters to Highway 89. A survival room was built in the garage there and a telephone was installed. Sierran winter storms are extremely severe at times and these items are essential for protection of staff dwelling at Sagehen in the winter.

The present capacity of the station will permit housing and feeding of twenty persons in the summer and six in the winter. The mess, laboratory, community room, and bachelors' buildings are completely insulated and winterized for year-round use. Sleeping accommodations for summer use are provided under canvas on wooden tent frames. Since there are many excellent camping sites available on the stream, many students as well as faculty members often camp out in summer.

Research Program

The main research effort at Sagehen is directed to long-term basic ecological studies of the factors governing the distribution and abundance of fishes. Ten separate sampling stations have been established over the 10 miles of stream and once each year these are pumped and drained, the fish counted, weighed, measured, and returned alive to the same section of stream from which they were removed. The 1955 season completed the first four years of sampling and analyzing these sections. Correlation with weather, stream flows, temperatures and other factors is being made but publication of the results will not be made until at least a minimum period of five years has been covered.

A second segment of the research program is concerned with winter studies. These constitute a broad expansion of winter studies begun in 1951 at the Convict Creek Experimental Station operated by the U. S. Fish and Wildlife Service near Bishop in eastern California. The main effort here is to identify and to measure the main factors involved in winter mortalities of stream fishes dwelling in high montane streams. This work was started over the winter of 1953-54 and winter studies are now a regular part of the Sagehen program.

In order to provide facilities for direct underwater observation of fishes, ice formation and dispersal, and thermocouple stations, two steel underwater observation tanks have been placed in the stream bed. The larger of these is placed in a fixed position in the stream bed and since some 5,000 pounds of rocks in racks at either end counteract buoyancy, it cannot be said to be portable. Four 15 x 23 inch plate-glass windows, two on each side, provide observation posts (Fig. 2). Thermocouple stations are set in various positions in the air, water and stream bed outside the tank. These copper-constantan thermocouples are attached to a selector switch and an ice bath standard inside the tank. A lead-covered cable runs some 400 feet from the tank to the laboratory where it connects with a potentiometer. Thus, two workers are required—one to make the observations in the tank and to select the stations where observations are being taken, with another in the laboratory to record the readings from the potentiometer. Telephones connect the laboratory with the tank.

The smaller, more portable underwater observation tank was installed in a riffle in the fall of 1955, where anchor ice forms abundantly. A cable from this tank also feeds into the potentiometer in the laboratory. Five thermocouple stations are operated at this tank as follows: (1) air, (2) water, (3) 12 inches in the gravel for ground water temperatures, (4) air-anchor ice where the thermocouple is alternately covered by anchor ice or exposed to the air, depending upon climatic conditions, and (5) solar radiation. A flat-plate, Gier and Dunkle radiometer is used for measurements of solar radiation above water. Below water radiation will be measured with a specially designed solarimeter recently developed on the Berkeley Campus by Professors Joseph Gier and R. V. Dunkle in Engineering.

Students have aptly termed the underwater observation tanks the "deepfreeze", and it is just that during sub-zero weather. An observer, even though heavily clothed, can stand only about 45 minutes lying in one of the tanks before he will have to return to the station headquarters to thaw out. Litter blankets and air mattresses help to reduce the chill and hardship but, even so, this kind of field work is strenuous to say the least.

Administration

The Sagehen Creek Project is administered as a regular division of the Zoology Department on the Berkeley Campus under what is termed the Zoology-Fisheries section. To July 1, 1956, the sum of

[1959]

Reprinted from Transactions of the Twenty-Fourth North American Wildlife Conference, March 2, 3, and 4, 1959. Published by the Wildlife Management Institute, Wire Building, Washington 5, D. C.

NEW HORIZONS IN STOCKING HATCHERY TROUT

Paul R. Needham
University of California, Berkeley

It has been my lot recently to summarize the returns from more than 244 separate trout planting experiments with marked trout. These are reported in approximately thirty-six separate papers (see bibliography) published principally in the United States and Canada. My intent here is not to repeat to you the monotonous statistics that emerge from such a study, but rather to present some of the over-all results of various stocking practices and to offer a few alternatives for consideration. After thirty years of investigation I think it is time that fisheries workers came to a few general conclusions with regard to planting of hatchery trout. The propaganda that hatcheries are the answer still sways the thinking of the majority of anglers.

Table 1 summarizes the survival rates grouped into six different categories. Fig. 1 illustrates the same materials in graphic form. A discussion of each of these follows.

1. *Lake Plants of Fingerlings Made at All Seasons:* Creeled fish averaged 7.4 per cent of numbers planted and ranged between 36.4 and 0.06 per cent respectively. Nineteen of the 32 plants gave re-

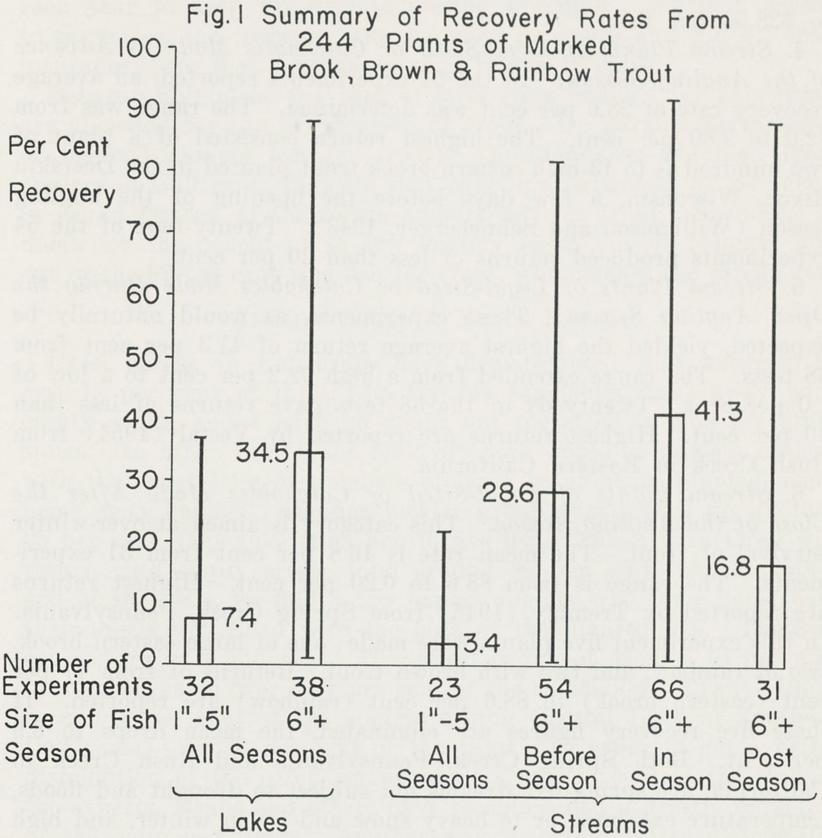
TABLE 1. SUMMARY OF RECOVERY RATES FROM 244 PLANTS OF MARKED BROOK, BROWN, AND RAINBOW TROUT AS REPORTED IN PUBLISHED PAPERS[1]

Category	Number of Separate Experiments Reported	Maximum and Minimum Percentages of Recovery	Average Recovery Rate	Remarks
Lake Plants of Fingerlings Made at All Seasons	32	36.4-0.06	7.40	Largest recoveries were obtained by Wales and German (1956) in Castle Lake, California, from 2-3 inch eastern brook planted following chemical treatment of the lake
Lake Plants of Legal-Sized or Catchables Made at All Seasons	38	88.4-1.10	34.5	Crecy Lake, New Brunswick, Canada, gave the highest returns following predator control operations (Smith, 1954)
Stream Plants of Fingerlings Made at All Seasons	21	14.0-0.00	2.5	Ten of the 21 experiments yielded less than a 1.0 percent return
Stream Plants of Legal-Sized Cathables Made in Advance of the Angling Season	54	82.0-2.60	28.6	A plant of 200 large eastern brook trout in the Deerskin River in Wisconsin gave the highest return (Willamson and Schneberger, 1943). Of the 54 experiments reported, 24 showed returns of less than 20 percent
Stream Plants of Legaly-Sized or Catchables Made During the Open Angling Season	68	92.2-1.00	41.3	Rush Creek, California, produced the highest reported returns (Vestal, 1954)
Stream Plants of Legal-Sized or Catchables Made After Close of the Angling Season	31	88.6-0.02	16.8	Highest returns in this group came from Spring Creek in Pennsylvania as reported by Trembly (1945)
Totals and Averages	244	Max. 92.20 Min. 0.00	27.2	Average is based on all sizes of fish planted regardless of species or time or place of planting

[1]Inclusion of survival data from around twenty-five days had to be omitted because of lack of pertinent information or artificial conditions of the experiments or because the subject matter did not pertain precisely to the problem at hand. Since no marked differences were observed in the survival rates reported for brook, brown or rainbow trout, the data for all three species are grouped together in this table.

coveries of less than 5.0 per cent. Highest returns were obtained by Wales and German (1956) where 2- to 3-inch eastern brook trout had been planted following chemical treatment to remove predators. Where populations of trout or other fishes are already present, survivals are usually less than five per cent.

2. *Lake Plants of Legal-Sized Trout Made at All Seasons:* Recoveries in this category averaged 34.5 per cent and ranged from 88.4 to a low of 1.1 per cent in 38 experiments. In this respect, they



were second to in-season plants of large trout in stream which gave an average return of 41.3 per cent.

3. *Stream Plants of Fingerlings Made at All Seasons:* The average recovery rate is 2.5 per cent from 21 experiments and they ranged from 14.0 per cent to zero. Ten of the 21 experiments yielded less than a one per cent return while four of them gave zero returns.

One experiment in Oregon is of interest here in connection with the planting of fingerlings in cold mountain streams. A plant of 30,363 marked 3-4 inch rainbow fingerlings was made in the Clackamas River near Portland, Oregon in the fall of 1946. Just nine fish (.03 per cent) returned from this plant. The cost of rearing the entire lot had to be charged against these, which brought the cost to $28.53 per fish.

4. *Stream Plants of Legal-Sized or Catchables Made in Advance of the Angling Season:* In the 54 experiments reported, an average recovery rate of 28.6 per cent was determined. The range was from 82.0 to 2.60 per cent. The highest return consisted of a plant of two hundred 7- to 13-inch eastern brook trout planted in the Deerskin River, Wisconsin, a few days before the opening of the angling season (Williamson and Schneberger, 1943). Twenty-four of the 54 experiments produced returns of less than 20 per cent.

5. *Stream Plants of Legal-Sized or Catchables Made During the Open Angling Season:* These experiments, as would naturally be expected, yielded the highest average return of 41.3 per cent from 68 tests. The range extended from a high 92.2 per cent to a low of 1.0 per cent. Twenty-six of the 68 tests gave returns of less than 30 per cent. Highest returns are reported by Vestal (1954) from Rush Creek in Eastern California.

6. *Stream Plants of Legal-Sized or Catchables Made After the Close of the Angling Season.* This category is aimed at over-winter survival of trout. The mean rate is 16.8 per cent from 31 experiments. The range is from 88.6 to 0.20 per cent. Highest returns are reported by Trembly (1945) from Spring Creek, Pennsylvania. In this experiment five plants were made; one of large eastern brook, two of rainbow, and two with brown trout. Returns of from 47 per cent (eastern brook) to 88.6 per cent (rainbow) are reported. If these five recovery figures are eliminated, the mean drops to 8.9 per cent. Both Spring Creek, Pennsylvania and Rush Creek in California, are spring-fed streams not subject to drought and floods, temperature extremes, or to heavy snow and ice in winter, and high recovery rates from such streams are not surprising. Where more average stream conditions prevail, much lower recovery rates are evident in the data analyzed.

Mullan (1958) reports winter carry-overs of from a high of 9.4 per cent to zero from twenty separate lots of eastern brook trout stocked in the streams of Cape Cod. These findings, with others, confirm the fact that over-winter carry-overs of stocked trout are negligible.

CATCHABLE PROGRAMS

Having looked at survival rates of all size groups of trout, let's take a closer look at the expensive catchable or legal-sized, "put and take" programs. To keep alive the ancient art of angling and to meet continually increasing demands for bigger and better fish, federal and state hatchery workers almost knock themselves out each year to keep up with increasing pressures. As they accede to pressures, the pressure gets stronger for more and more "creel insurance," for that is precisely what it may be called.

Between 65 and 85 per cent of most state budgets for gamefishes are allocated for the propagation of trout. Do parallel percentages of licensed anglers fish for trout? Questionnaires obtained from anglers in California indicate that only approximately 30 per cent, in round figures, of California anglers fish for trout. Spending so much for the benefit of so few anglers seems out of balance, and out of the 30 per cent who fish for trout, who catches the catchables?

Angling Skill A Major Factor

Creel checks in California have demonstrated that between 65 and 75 per cent of those who try for catchables come away with empty creels, and I have no doubt but the same is true for other states. In other words, the bulk of those would-be anglers enticed with the sweet song of numbers of large trout being planted, come home emty handed. Another luckier group that makes up another 25 per cent, may take from one to five fish. These, with those who return with empty creels, total around 90 per cent. At the other end of the scale, we find a few expert anglers who come home with their creels well filled with the bulk of the planted fish. These of course, are in a minority. This select group of around 10 per cent in number, catch over fifty per cent of the catchables. Evans (1957) reports 3 per cent of the anglers fishing Crystal Lake in Southern California, took 30 per cent of the trout. In order to get a better distribution of the catch among anglers and to control the skill of the experts, Evans and others have recommended a drastic reduction of the daily bag limits. Another way to obtain better distribution of catchables is to plant them in lakes as is now being done in many states. A Nevada worker told the writer that it was his opinion that catchables should only be planted in lakes. If the lakes are of large size, the fish become widely dispersed which, in turn, reduces the concentration of anglers usually seen after the fish are planted in streams. Those surviving grow much larger and more like wild trout in their fighting ability.

Trout At A Bargain

Since 1948 over 4.3 million dollars has been expended in California on hatcheries. This has increased the production of catchable trout over 325 per cent. This is a large increase, but we doubt if the quality of the sport has been equally improved. In a way it might be said that by planting catchables we are competing directly with the operators of "fish-out" ponds where you catch your trout at so much an inch or per pound. The main difference is that it's cheaper to catch hatchery-reared fish planted by the state. Indeed, the state could save a lot of money by not going to the cost of planting catchables at all. They could set "fish-out" ponds aside at each hatchery where the angler, for a fee, could indulge his sport with assurance and where a 100 per cent return to the creel would be assured. This would have the practical advantage of having those anglers who catch catchables pay for them too. Now, many of us who prefer the quiet of a wild stream are taxed to support the catchable program without sharing its benefits. Assuming that catchables cost 20 cents apiece as they are planted, and assuming a 50 per cent mortality after planting, then each fish placed in the creel costs some 40 cents apiece. If your angling license cost you $3.00 then, theoretically at least, you have had more than your money's worth after you have caught eight of them.

Cases are on record where single families consisting of two adults and two children fishing on two licenses (no fee for children) have caught 60 (bag limit 15) catchable trout in one day. A good bargain this, where for a mere $6.00, $24.00 worth of trout are obtainable. But this is for only one day. If two bag limits are allowed each person each week, and if the season extends for twelve weeks, the same lucky couple can legally capture 1440 catchables having a net value of $576, and all for the token fee of $6. There is some consolation here, for probably this would not happen because analyses of creel data have shown that the best fishing for catchables in streams occurs immediately after the fish are planted, and falls away rapidly to zero within from 8 to 16 days following planting (Jensen, 1958). Thus unless our couple could stay right behind the fish planting truck, they would not be able to maintain their earlier predatory record.

Hatchery Trout Unfit for Survival in Wild Waters

One of the reasons for the low survival of catchables in wild waters is that, being hatchery reared, they are poorly adapted to compete and survive with naturally propagated fishes that had to "learn the hard way." Being protected in hatcheries for from one to two years, spoon-fed, and accustomed to an easy life, when placed on their own they prove ill adjusted physically and genetically, and are unable to withstand the severe conditions of an independent existence. This has been proven by the appallingly low returns cited above and the fact that apparently a natural mortality rate of some 10 to 30 per cent occurs immediately after each plant for no apparent reason. Possibly the reason for low survivals is that we are planting strains of highly inbred, mongrel stocks which, because of their hatchery life, are physical misfits in wild environments. Decades of selection for hatchery conditions would certainly be poor preparation for survival in competition with wild trout. The evidence derived from survival studies cited here leads one to believe that the trout produced by present-day hatcheries are in no way the equal of wild trout, and the end product should be used principally for planting in fish-out streams or ponds or slaughtered and packaged for immediate consumption.

Delayed Mortality

Where resident trout populations are already present in streams, losses of hatchery planted trout are often immediate and heavy as was noted above. This has been termed "delayed mortality." In seeking the causes of such losses, Miller (1958) tentatively indicated that they might result from competition with wild trout for living space or niches rather than for food, forcing the introduced fish to constant, excessive exercise resulting in death by either acidosis or starvation. This idea stems from the fact that he found significant differences in blood lactic acid levels between hatchery trout with and without competition from resident trout.

Observations on trout behavior made by using an underwater tank (Needham and Jones, In Press) indicate that trout are quite territorial, tending to occupy the same general areas for considerable periods of time. We know of one large brown trout that occupied the same hole in a beaver pond in Sagehen Creek for five years, remaining there despite heavy floods and other drastic environmental changes. It is rapidly becoming apparent that efforts to create fish "tenement districts" by dumping large numbers of trout into short stretches of stream, fail both because of lack of "living room" and ability to compete with resident forms already present. The excessive movements and resulting fatigue described by Miller could result from psychological frustration by virtue of crowding the fish into a new, strange, and limited environment.

Quality of Sport and Angling Ethics

The basic question here is this: is the quality of the sport improved regardless of where catchables are planted? I think not. To have to carry your own rock to stand on, to fish elbow to elbow with hordes of fishermen is not providing high quality sport. In the mad scramble to get their money's worth of catchables just dumped from the fish truck, the gentle art of angling becomes degraded and despoiled by greedy and unsportsman-like "meat" fishermen. Old-timers who are used to the wily, naturally propagated brown trout of the Deschutes or Ausable rivers, prefer fishing-room, if you will, with the bulk of the scenery undisturbed by hundreds of eager-eyed anglers using hamburger, liver, or cheese for bait. As the plantings of catchable trout increase, the quality of the sport decreases. In following the fish planting truck are we properly indoctrinating our youth in the principles of true sportsmanship and knowledge of proper angling ethics? Certainly it makes no difference whether a trout is caught on a dry-fly or a worm, but it is questionable whether our sons can learn proper stream etiquette by standing in line at a fish-out pond or crowded by hordes of anglers on the edge of a fish-out stream. The planting of catchables is the cause of the crowding. On a stream where no catchables are planted you may see a lot of anglers but usually not elbow to elbow and the practice of stream ethics there reflects a higher standard of angler effort. You seldom see fist fights, and if you find an angler on a small pool ahead of you, you respect his rights and go around it to the next likely spot.

The modern tendency of many states continually to pyramid catchable trout programs at the expense of habitat improvement or research seems indefensible on a long-term basis. We have been kidding ourselves into believing that we can improve the quality of the angling by increasing the supply of fish above and beyond those provided by natural reproduction. The quantity of fish has increased while the quality of the fishing has sadly deteriorated. As one Southern California angler put it: "The truck arrives at 11:00 a.m. with hordes of cars following, the stream is fished out by 2:00 p.m. and dry by 4:00 p.m. if somebody decides to irrigate."

Natural Propagation

A good idea of just how effective natural propagation can be is illustrated by research done at the Sagehen Creek Wildlife and Fisheries Project located near Truckee, California, in cooperation with the California Department of Fish and Game A creel census operated on the upper five miles of Sagehen Creek over the past six years has shown that this small stream produces roughly between 1600 and 3200 trout weighing between 162 and 287 pounds each year to anglers—all of which come from natural propagation, since stocking of hatchery fish was stopped there in 1951. By annually sampling fish in the stream itself in a series of ten short sections by pumping and draining, estimates of total fish available for the catching have been made The exploitation rate of fish four inches and up in length has averaged below 45 per cent of those available each year. Catches have averaged between 1.08 and 1.88 fish per angling hour which is indicative of good fishing provided solely by natural spawning. There is good escape shelter and the exploitation rate evidently permits survival of adequate breeding stocks each year. These are providing all the trout necessary for the "room and board" in Sagehen Creek. Many waters like Sagehen Creek that do not need hatchery fish at all are still being stocked.

Recent trends towards setting aside certain lakes, streams or sections of streams for fly-fishing only or where "catch-and-put-back" areas have been designated, will do much to improve the quality of the angling. If artificial lures and barbless hooks are required in such areas, a lot of fishermen will be able to have much excellent sport, including the experts. And that basically is what we are trying to provide.

Designation of Catchable Waters

Fish and Game officials know that from 75 to 85 per cent of all trout creeled originate from natural spawning, not hatcheries. This being the case and since natural propagation is carrying the main burden so far as angling is concerned, why not give more funds for research and experiment to aid and abet this process? Habitat improvement to increase natural spawning seems to us to offer a new and largely unworked field. I refer here not to the removal of log jams and other barriers to spawning migration of anadromous fishes, which is a useful tool, but rather to the details of actually creating new and greater expanses of spawning beds in suitable, accessible areas. We have no reports of studies along this line except in a few isolated areas. If work is started along these lines, there will be less money for rearing catchables. This means a ceiling must be set for the hatchery program that will leave sufficient funds for badly needed new and basic attacks. If such a ceiling is to be set it will first be necessary to designate certain lakes, whole streams, or sections of streams as "fish-out" or "catchable trout" areas and determine the number of fish that will be required annually to stock these waters. The water area of suitable habitat will never be higher than it is today for the planting of catchables. It is rapidly becoming less as water use becomes greater so that in the long pull over the years a gradual decrease in the catchable program can be forecast.

Designation of "Natural Fish" Waters.

After designation of the "catchable" waters, all other lakes, streams or sections of streams might be declared "natural fish" waters in which most of the reliance for providing fishing will be placed on natural propagation alone. I use the word "most" advisedly. It is well known that in some lakes lacking suitable spawning inlets or outlets, the planting of fingerlings may help to maintain angling and stocking of such waters must of necessity be continued. Where "winter-kill" of all fish life occurs, re-stocking is the only remedy. The same would apply to streams denuded of fish life by pollution, flash-floods or other causes. Streams designated as "wildfish streams" would never require stocking except where catastrophes occur. Stocking would only be used where it has demonstrated its effectiveness.

Stocking for Reproduction Successful

Stocking game animals or fishes for the purpose of establishing self-sustaining populations is good, and its value as a management tool has been proven many times. The introduction of brown trout from Europe and pheasants from China is proof of this principle. But where all suitable habitat has already been stocked, the problem then becomes one of proper use of the hatchery or game-farm products in areas already containing "wild" populations. Thousands of streams and lakes that are now producing fine fishing were barren of fish originally. For this we must thank the early-day fish culturists who saw to it that suitable species were established. But that day is gone now and there are no more barren lakes or streams available for stocking. How long are we going to let wishful thinking and the fond belief in hatcheries continue to bar further progress? The application of facts derived from research will provide the future answers.

In closing I am reminded of the farmer who was asked if he could play the violin. He replied, "I don't know, I never tried." In fisheries management there are many things that we don't know and have never tried. The blind faith displayed by the angling public in hatcheries must be replaced by broader concepts disseminated from more detailed knowledge of the natural behavior and survival of fishes. We are still in the "Model T" days in so far as our understanding of the physiology and genetics of gamefishes is concerned.

It is easy to get millions for hatcheries but hard to get even a pittance for research. How long can such a single "yard-stick" bar further progress? If the angling needs of the future are to be met, if we are to obtain the most from our shrinking habitats and show parallel progress with other fields of endeavor, a drastic change in attitude and programs is essential. Only then will we be able to live in a state of piscatorial rectitude.

LITERATURE CITED

Burdick, Milton E., and Edwin L. Cooper
1956. Growth rate, survival and harvest of fingerling rainbow trout planted in Weber Lake, Wisconsin. Jour. Wildl. Mgt., 20(3): 233-239.

Chamberlain, T. K.
1943. Research in stream management in the Pisgah National Forest. Trans. Am. Fish. Soc., Vol. 72, 1942, 150-176.

Cooper, Edwin L.
1953. Returns from plantings of legal-sized brook, brown, and rainbow trout in the Pigeon River, Otsego County, Michigan. Trans. Amer. Fish. Soc., Vol. 82, 1952, 265-280.

Curtis, Brian
1951. Yield of hatchery trout in California lakes. Calif. Fish and Game, 37(2): 197-215.

Evans, Willis A.
1957. A study of the 1952 trout fishery, Crystal Lake, Los Angeles County. Calif. Dept. Fish and Game Inland Fish. Adm. Rept. No. 57-29, 21 pp.

Gee, Merle A.
1942. Success of planting legal sized trout in the Southwest. Trans. Seventh No. Amer. Wildl. Conf.: 238-244.

Hale, John G.
1952. Results from plantings of marked yearling brown trout (*Salmo trutta fario Linnaeus*) in the Sucker River and the west branch of the Split Rock River, and marked yearling brook trout (*Salvelinus fontinalis Mitchill*) in Sucker River, Minnesota, 1951. Minn. Bur. Fish. Invest. Rept. 118: 11 pp.
1954. Investigations on trout catch and populations in the west branch of the Split Rock River, Lake County, Minnesota, 1951 to 1953. Minn. Dept. of Cons., Div. of Game and Fish, Bur. Fish. Investigational Rept. 148: 14 pp.

Hale, John G., and Lloyd L. Smith, Jr.
1955. Results of planting catchable-size brown trout, *Salmo trutta fario L.*, in a stream with poor natural reproduction. Prog. Fish. Cult., 17(1) Jan. 1955: 14-19.

Hazzard, Albert S., and David S. Shetter
1939. Results from experimental plantings of legal-sized brook trout (*Salvelinus fontinalis*) and rainbow trout (*Salmo irideus*). Trans. Am. Fish. Soc., Vol. 38, 1938: 196-210.

Holloway, Ancil D., and Thomas K. Chamberlain
1942. Trout management and stocking results in the national forests of the southern Appalachians. Trans. Seventh No. Amer. Wildl. Conf.: 245-249.

Holloway, R. C.
1947. Lake management studies in Oregon. Trans. Amer. Fish. Soc., Vol. 77: 105-113.

Jensen, Paul T.
1958. Catchable trout studies in region II. Calif. Dept. Fish and Game. Inland Fisheries Adm. Rept. No. 58-1: 39 pp.

Lord, Russell F.
1946. The Vermont "test-water" study, 1935-1945 inclusive. Vermont Fish and Game Service, Fish. Res. Bull. 2: 110 pp.

Miller, Richard B.
1958. The role of competition in the mortality of hatchery trout. Jour. Fish. Res. Bd. Canada, 15(1): 27-45.

Mullan, James W.
1955. An evaluation of Massachusetts' trout stream fishery. Proc. Northeast Sect. Amer. Fish. Soc., 1955.
1958. The sea-run brook trout fishery of Cape Cod. Mass. Dept. Fish and Game, Bull. No. 17: 25 pp.

Needham, P. R.
1937. Methods of measuring anglers' catches in inland waters. Copeia, 1937, No. 1: 41-48.

Needham, P. R., and F. H. Sumner
1941. Fish management problems of high western lakes, with returns from marked trout planted in Upper Angora Lake, California. Trans. Amer. Fish. Soc., Vol. 71: 249-269.

Needham, Paul R.
1949. Survival of trout in streams. Trans. Amer. Fish. Soc., 1947, 77: 26-31.
Needham, Paul R., and Albert C. Jones
1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology (In Press).
Nesbit, R. A., and J. A. Kitson
1937. Some results of trout tagging in Massachusetts. Copeia, 1937, No. 3: 168-172.
Newell, A. E.
1958. Trout stream management of the Swift River watershed in Albany, New Hampshire. N. H. Fish and Game Dept. Survey Rept. No. 7: 40 pp.
Seaman, E. A., and R. F. Stephens
1950. Percentage returns of marked trout in two West Virginia streams. Prog. Fish. Cult., January 1950, 12(1): 29-31.
Shetter, D. S.
1939. Success of plantings of fingerling trout in Michigan waters as demonstrated by marking experiments and creel censuses. Trans. No. Amer. Wildl. Conf. 4: 318-325.
1947. Further results from spring and fall plantings of legal-sized hatchery reared trout in streams and lakes of Michigan. Trans. Amer. Fish. Soc., Vol. 74: 35-58, 1944.
Shetter, David S., and Albert S. Hazzard
1942. Planting "keeper" trout. Mich. Cons., 11(4): 3-5.
Smith, Lloyd L., Jr.
1941. The results of planting brook trout of legal length in the Salmon Trout River, northern Michigan. Trans. Amer. Fish. Soc., 1940. Vol. 70: 249-258.
Smith, Lloyd L., Jr., and Beatrice S. Smith
1945. Survival of seven to ten inch planted trout in two Minnesota streams. Trans. Amer. Fish. Soc., Vol. 73, 1943: 108-116.
Smith, M. W.
1954. Planting hatchery stocks of speckled trout in improved waters. The Canadian Fish Culturist, August 1954, issue 16: 1-5.
Swartz, Albert H.
1950. Report on the results from trout stocking in the Deerfield River. Journ. Wildl. Mgt., 14(2): 183-189.
Thorpe, Lyle M., H. John Rayner and Dwight A. Webster
1947. Population depletion in brook, brown, and rainbow trout stocked in the Blackledge River, Connecticut, in 1942. Trans. Amer. Fish. Soc., Vol. 74, 1944: 166-187.
Trembley, G. L.
1945. Results from plantings of tagged trout in Spring Creek, Pennsylvania. Trans. Amer. Fish. Soc., Vol. 73, 1943: 158-172.
1954. Fishing results on Upper Wood Pond. Penn. Angler, 23(3): p. 2.
Vestal, Elden H.
1943. Creel returns from hatchery trout in June Lake, California. Calif. Fish and Game, 29(2): 51-63.
1954. Creel returns from Rush Creek test stream, Mono County, California, 1947-1951. Calif. Fish and Game, 40(2): 89-104.
Wales, J. H.
1946. Castle Lake trout investigation, first phase: interrelationships of four species. Calif. Fish and Game, 32(3): 109-143.
1947. Castle Lake trout investigations: 1946 catch, and chemical removal of all fish. Calif. Fish and Game, 33(4): 267-286.
Wales, J. H., and E. R. German
1956. Castle Lake investigation, second phase: eastern brook trout. Calif. Fish and Game 42(2): 93-108.
Williamson, Lyman O., and Edward Schneberger
1943. The results of planting legal-sized trout in the Deerskin River, Vilas County, Wisconsin. Trans. Amer. Fish. Soc. Vol. 72, 1942: 92-96.

DISCUSSION

CHAIRMAN SCHEFFER: Dr. Needham has spoken to us of objectives, standards, and ideals. I like to hear a man speak up for ideals because I think that the idealist, far from being the impractical person that we often think of him as, is actually one of the most realistic creatures among us.

Are there comments on Dr. Needham's talk in the last five minutes available to us?

DR. CLARENCE COTTAM: What would be the comparable percentage of fish produced in the wild, but which have been tagged, and then turned loose? Would that be comparable at all?

DR. NEEDHAM: That would be comparable.

Unfortunately, we have not the data on that. The man who has done the most work, Dr. Richard Miller, is not here.

There are a number of data that are available on the experimental fish on the comparison of wild fish, but we have not accumulated the mass data that would be necessary for this chart. It would be very nice to show the comparison for wild fish under two experiments run under the same type of conditions. I wish I had it.

MR. ALBERT HAZARD [Pennsylvania Fish Commission]:

Paul, as you know, I agree with your philosophy and we should maintain fishing where we can by natural means.

But here in the East, with our growing population, with the growing pressure, I am now quite convinced that we cannot rely on natural reproduction, that even if we improve all of our streams and lakes to the limit, we still will not be able to provide fishing, or adequate fishing recreation.

I did not say fish catches. I believe there are ways in which we can utilize our hatchery production to better advantage than we are now doing.

I would go along with you that we ought to do most of our stocking in the poorer streams, the marginal streams, where we do not have the competition from the wild fish. We will get better returns, I am sure. They will also spread the fishing opportunities over the State.

The other idea is to limit the kill. This past year in Pennsylvania, we had a stream in which fishing was permitted, that is, unlimited fishing during the season. One could catch all the fish he wanted to, but he could not kill any in that branch of Youngman's Creek.

That experiment has proven out very well, and will be continued this year. At the end of the season, when we know the population we have through stocking, it is likely we will also install a trophy fish size as they have on the fish for fun streams, in the Great Smokies National Park. I hope the biologist who is associated with that program is present and will comment also.

DR. NEEDHAM: I want to compliment you, Al. I had that also in my paper, but time was pressing me so I did not mention it.

But I think you are a hundred per cent right. We should be emphasizing sports values, and one way to do it, will be told to you by Mr. Wallace who is coming up to the microphone.

MR. WALLACE [National Park Service]: For about four years down in the Great Smokies Mountains National Park, we have had an experiment which has been conducted in cooperation with the U. S. Fish and Wildlife Service.

We started out with two streams that were for fishing for fun only, fish all you want but return the fish.

We have expanded that into four streams now. These four streams are open all year around rather than just during a limited fishing season. Down there they have found that in these streams, the anglers are able to catch up to 11 fish per angler-hour, as compared in nearby streams where they can keep the fish.

There they only get about a half a fish per hour.

So it has increased the sport, the recreational aspect, and it has met with a great deal of public enthusiasm in that area.

Now, it is not a thing that is going to work in all waters, but it is one possible solution. Al Hazard, of course, proposed this idea several years ago, and it came out first in *Sports Afield*, and during the past year there have been a couple of follow-up stories in *Sports Afield*, about the first applications of this theory.

DR. NEEDHAM: Thank you, Mr. Wallace. I think if we get to the point where we can really emphasize the sport value, the intangible recreational values, the joy of being on the stream and try and educate our customers to get away from the meat fishing, this setting aside of these streams as Dr. Hazard and the last speaker mentioned. Then by fly-only streams with barbless hooks, I think we can create a lot of good fishing, a lot of fishing of high quality, and we can get away from the rather disgraceful, greedy attitude of the meat fishermen following planting trucks and degrading an otherwise noble sport.

REPRINT FROM
CALIFORNIA FISH and GAME
"CONSERVATION OF WILDLIFE THROUGH EDUCATION"
VOLUME 47 JANUARY, 1961 NUMBER 1

OBSERVATIONS ON THE NATURAL SPAWNING OF EASTERN BROOK TROUT[1]

PAUL R. NEEDHAM
University of California, Berkeley, California

INTRODUCTION

In late September and early October, 1959, I witnessed all phases of the natural spawning of eastern brook trout, *Salvelinus fontinalis* (Mitchill), from an underwater observation tank at the University of California's Sagehen Creek Wildlife and Fisheries Station. This station is located at an elevation of 6,400 feet in the Sierra Nevada mountains, 27 miles north of Lake Tahoe in the Truckee River drainage.

As pointed out by Fabricius (1950), it is important that the releasing mechanisms of spawning and their sign stimuli be fully understood, for these determine the potential scope of environmental variations within which a species of fish is able to spawn. Knowledge of the spawning requirements of any given species will provide a sound basis for stocking in suitable waters where the greatest possible benefit can be derived through natural propagation.

Previous descriptions of the spawning of salmonids are included in the following papers: Belding (1934) on Atlantic salmon; Briggs (1953) on silver and king salmon and steelhead trout; Cramer (1940) on cutthroat trout; Fabricius and Gustafson (1954) on the Arctic char; Greeley (1932) on brook, brown, and rainbow trout; Hazzard (1932) on eastern brook trout; Hobbs (1937) on quinnat salmon, brown and rainbow trout; Jones and Ball (1954) on brown trout and Atlantic salmon; Jones and King (1949 and 1950) on Atlantic salmon; Needham and Taft (1934) on steelhead trout; Needham and Vaughn (1952) on the Dolly Varden char; Schultz et al (1935) on kokanee salmon; Smith (1941) on cutthroat and eastern brook trout; and Stuart (1953) on the brown trout. The observations of Fabricius and Gustafson (1954) and Jones and Ball (1954) were made using observation tanks or aquaria with recirculating water supplies. Jones and King (1949 and 1950) used an underwater observation tank built on the side of the River Alwen, a tributary of the Welsh Dee. Needham and Jones (1959) used the same underwater observation tank from which the observations described in this paper were made. Except for the five papers just cited, the majority of the observations reported were made from above the water where it is most difficult to properly conduct observations or to interpret them accurately.

Figure 1 indicates the physical arrangements in the pool where the observation tank is located. Two water level control dams fitted with flashboards made it possible to control depths over a range of about

[1] Submitted for publication May, 1960.

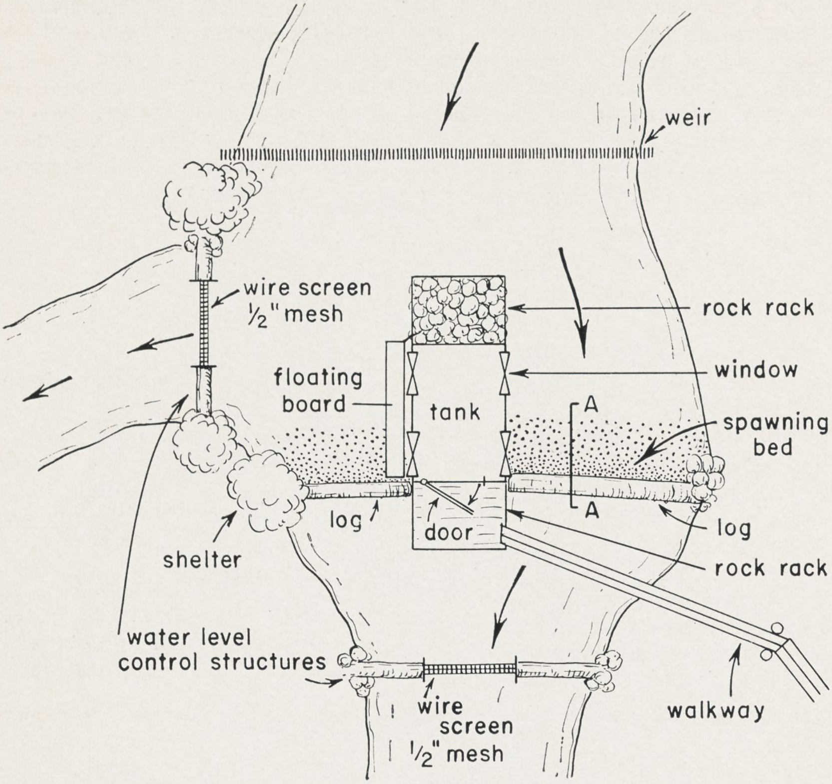


FIGURE 1. Physical arrangements at the underwater observation tank in Sagehen Creek, September 4 to October 23, 1959.

one foot. One-half-inch mesh screens fitted over these prevented escape of the fish downstream. A weir was placed about four feet upstream from the tank across the tank pool to confine the fish to the tank area. The tank and its uses were described by Needham (1956), and Needham and Jones (1959).

CONSTRUCTION OF SPAWNING BEDS

Two spawning beds were installed beside the two downstream windows on each side. These were constructed as follows: two logs were cut of suitable diameter and length to run horizontally from the posterior edge of each downstream window into the stream-bank on each side. A canvas apron about four feet wide was nailed on each log for its full length. The logs were then placed in the stream on each side of the tank so that the canvas could be laid flat on the stream bottom on the upstream sides of the logs. Each log was placed so that the line of nails where the canvas was fastened came in the middle of their upstream sides. The logs were securely fastened to the streambed by nailing to stakes driven in the bottom on their downstream sides, by wedges driven against the rock racks, and by heavy rocks placed on the stream-side ends of each. Clean, water-washed gravel was then dumped on top of the canvas, and carefully spread to the top of each log and diagonally across each window. The canvas apron lying on the bottom of the upstream side of each log forced the water to upwell through the gravel and over the log. Most of the gravel for the spawning beds was stream-worn and well rounded, and averaged from one-quarter of an inch to about one inch in size. Figure 2 illustrates a cross section of one of the spawning beds.

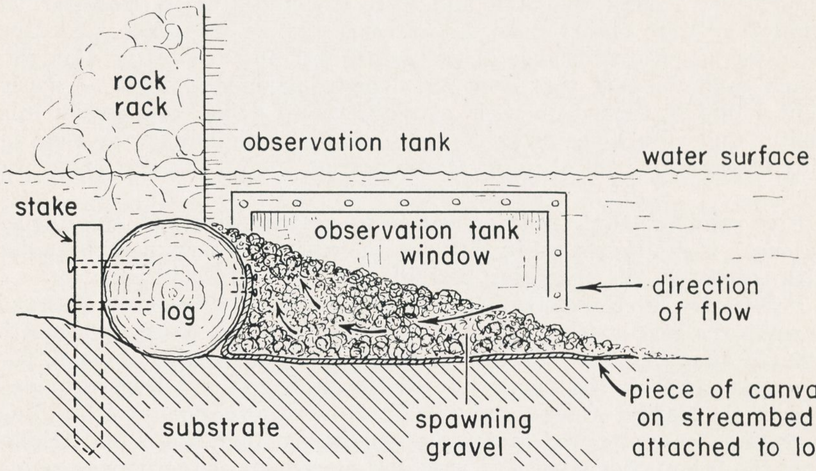


FIGURE 2. Cross section of artificial spawning bed next to observation tank window, Section A-A in Fig. 1.

Six inches of water was maintained over the logs supporting the beds on each side of the tank. As Figure 2 indicates, the depth increased gradually upstream so that at the upstream ends of the beds the depth was about one foot. The deepest part of the tank pool was approximately 22 inches, but this area was out of range of vision from the tank windows and was located just in front of the upstream rock rack. Fish, when frightened, frequently disappeared upstream in the direction of deeper water where they could not be seen. Lack of a wide area of vision is one of the real limitations in the use of a small observation tank. It would be of great value to observe the activities and behavior of fishes over much broader underwater areas.

That the spawning beds were suitably constructed was evidenced by the fact that the brook trout soon moved over them and began their normal breeding behavior. The observations reported here are largely based upon the behavior of a single pair, the male of which was around 12 inches in total length. He bore a jaw tag on the right side of his dentary bone, which had been placed there in 1954, and thus was easily distinguished from other males during breeding. His breeding color consisted of brilliant red on the belly, fiery red lower fins with the usual white bands followed by black on their anterior margins, and strong teeth developed on an upturned lower jaw. The female was about nine inches in length, and her breeding coloration was much duller than that of the tagged male.

Five other males and three other females had been placed in the tank pool. Two of the excess males were also fairly large fish, ranging about 10 inches in length, while the other three were from 5 to 7 inches in length. Three sexually mature brown trout (*Salmo trutta*) had also been placed in the tank area, of which one was a female about 10 inches, and two were males approximately 14 inches and 16 inches in length. The brown trout in the pool were never observed to spawn in the daytime. Evidently, they sensed the artificial nature of the arrangements around the tank and were suspicious of it. However, at night they were observed on the extreme edge of the south spawning bed; and much disturbance of the gravel was observed after daylight, which gave evidence that they were spawning only at night. A flashlight suddenly turned on them at night would drive both species into shelter underneath the roots of a tree on the bank side of the redd or into deeper water out of range of observation behind the weir above the tank.

Five rainbow trout (*Salmo gairdnerii*) between five and nine inches in length were also placed in the area, in order to observe their behavior with respect to the spawning activities of the eastern brook trout.

Practically all the spawning activities reported here were observed through the rear south-window of the tank and took place underneath a board that had been floated on the surface to provide shelter. The spawning area on the north side of the tank had not been provided with such floating shelter and was little used, although nest building operations were observed there occasionally. Another factor that frightened the fish on this spawning area was movement of the persons going in and out of the tank via the walkway that passes some three feet over one corner of the area. Means of screening movements of personnel, such as the tar-paper blinds used by Needham and Taft (1934) and Smith (1941), make it possible to conduct observations without disturbing the fish.

A strobe light used in taking pictures did not unduly disturb the fish except that, early in breeding activities, the big male that mated with the female described above would sometimes jerk back three or four inches from his place beside the female immediately after the flash. Later at peak of spawning, however, no reaction was noted by this or other fish to the flash of the strobe.

PRE-SPAWNING ACTIVITIES

On September 25, the tank pool was stocked with the trout noted above. They were taken using a direct current shocker from closely adjacent stream sections. Within two hours they had evidently completely recovered from the shocking and handling, and two of the larger males began courtship behavior. In its early stage, this consisted of attempting to drive or to guide a female from the deeper water near the upper windows of the tank downstream to the spawning beds in shallower water beside the downstream windows. To do this, he usually swam close beside the female and slightly ahead of her on her upstream side, gently turning her toward the redds. Frequently the female refused the escort and turned back to deeper water. Evidently, the females were still in the process of maturing; for a week later such actions to herd the females toward the redds were unnecessary, and they remained constantly over the redds except when frightened.

One characteristic feature of pre-spawning activities of the female was searching or looking over the bottom for a suitable spawning area. She arched her back and held her head close to the bottom as her eyes were seen to turn downward in close inspection of the gravel. While doing this, she was constantly courted by the male. A similar type of searching is described for the female Arctic char by Fabricius and Gustafson (1954) and by Jones and Ball (1954) for the brown trout and Atlantic salmon. The tagged male spent most of his time driving off other males, not sharing at all in the cutting of the redd with the female. In addition, he frequently courted the female by suddenly darting alongside of her and quivering slightly. He also swam over and under her, frequently rubbing his fins against her as he did so. The movement of both fish is practically constant—the female being occupied with cutting the redd, and the male with courtship actions and aggressively driving other males away. The female shared in the repulsion of other males that constantly gathered near the nest area evincing much interest and evidently intent upon sharing in the spawning act.

The female in cutting, turns on her side and by means of rapid, vertical movements of her tail fin, sucks gravel, silt and debris from the bottom. The smaller stones and silt are swept away by the current but the larger quickly settle to the bottom, forming a mound just below the bed. Actually, this operation appears somewhat like a swimming motion made while turned on her side. The head also moves up and down in the same direction as the tail, but its movement is less pronounced than that of the tail. The force of the cutting motion may cause the female to move a foot or so beyond the area being cut, but repeated digging movements soon produced a depression four to six inches in depth for the reception of the eggs. Jones (1959), who took slow motion films of the cutting action of the Atlantic salmon, *S. salar,* states that with this species, ". . . it is apparent that the female starts a cut from her normal position, that is with head upstream, body on an even keel and almost parallel to the river. She then turns over on her side, usually by first rotating her caudal fin so that it rests almost flat on or near the gravel and then by a lesser rotation of the body, which in this phase is tilted at about 45 degrees. Then the posterior half of her body is bent sharply downwards and her caudal fin rests fanned out on or near the gravel. . . . From this position follow rapid straightening (the upstroke) and bending (the downstroke), so that the posterior region of her body is thrust vigorously upwards and downwards from and to the gravel. This action of flexing and straightening the body is repeated several times in rapid succession. In the more vigorous cutting movements the anterior part of the body may be more bent, so that the fish is an inverted U. Throughout these movements, the pectoral, pelvic and dorsal fins are erected, and the mouth is slightly opened. I believe that the vigorous downstroke of the posterior half of the body thrusts the water against the gravel with sufficient force to loosen it. Certainly the upward flexion sucks gravel upwards: individual stones can be seen to follow the tail-fin until they are caught in the current and carried downstream. The complete action of flexing and straightening of the body constitutes one cutting movement, and a complete series of such movements, beginning and ending with the fish in its normal position on an even keel, is called a cut. A weak cut consists of only a few slow and languid cutting movements: a strong cut may consist of as many as a dozen vigorous cutting movements in rapid succession, at the rate of about three or four a second. The female tests or feels the effect of her cutting by means of her anal, caudal and pelvic fins. . . .'' The cutting action of the brook trout appeared similar in all respects to that of the Atlantic salmon.

The trembling or quivering movements observed in courtship have been shown by Fabricius and Gustafson (1954), to actually be very swift undulations. This was determined from slow-motion pictures. They say (p. 74) that, ''. . . waves of lateral contortions travel rapidly from the cranial to the caudal end of the body.'' During nest-cutting operations the tagged male accompanying the female became highly annoyed at a five-inch male eastern brook trout that was persistently trying to get into the nest area. The annoyance apparently came to a head when he seized this small fish across the back between his jaws, released him for a moment, and then seized him again in the same fashion and shook him much like a dog shakes a rat. It appeared first that he was going to eat him, but this did not occur. Close observation of the small fish next to the window did not reveal any teeth marks or any injury. The attack did not daunt him in the least, for he continued to harass the large male.

As noted by Needham and Taft (1934), Smith (1941), and other workers, breeding activities continued both day and night. Changes in the shape and size of the redds were noted from day to day—changes which could only have been made at night when observations could not be made.

THE SPAWNING ACT

This spawning act was first seen on October 10, 1959, at 12.40 p.m. The female was observed to drop her anal fin deeply into the pit, arching her tail at the same time. The male promptly took his place beside her. Both opened their mouths wide and appeared to tremble while milt and eggs were emitted simultaneously, the entire act lasting no longer than about one second. None of the other males present were seen to dart into the nests on the opposite side of the female and share in the spawning act. Smith (1941) reports observing two males sharing in the spawning act in one out of three spawning acts observed by him.

Because the male took his position on the right side of the female between the window and the female, and because of the white cloud of milt extruded, it was impossible to observe the eggs falling into the bottom of the nest. However, the pale yellow eggs could be seen clearly in the bottom of the pit after water currents had washed away excess milt. The milt was observed to hang in the current eddies in the pit, spreading laterally and even upstream a bit before finally disappearing. The bottom of the pit was some four inches below the edges of the nest. This provided a pocket of quiet water, where the eggs were dropped and where fertilization must have occurred almost instantaneously. Hobbs (1937), Cramer (1940), and Smith (1941)—all observed the cloud of milt, but only Smith noted the spread of the milt upstream and sidewise in the nest because of current eddies.

The position taken by the female in the actual spawning act was termed "a crouch" by Jones and Ball (1954) in observations of the spawning of Atlantic salmon and brown trout. They also observed that the orgasm lasted only one or two seconds in brown trout, while that of the salmon required approximately 10 seconds. About a second was required for completion of the act in the eastern brook trout; and in this respect, they parallel brown trout.

Fabricius and Gustafson (1954, p. 99), in their description of the spawning act of the closely related Arctic char *Salvelinus alpinus,* state that when ready to spawn, "the female shows a signal movement which could be called anchoring. She suddenly stops in the center of the nest pit, lowers her anal fin down into some crevice in the bottom, bends her body backwards, trembles and opens her mouth. The male responds by swimming up parallel to her, and both fishes swim side by side across the pit in a spawning act, squirting out their sexual products." On the same page they also state that, "After 1 to 5 successive spawning acts the female performs snake-like undulating movements," to cover the eggs with gravel. In contrast with their observations, the pair of eastern brook trout observed in Sagehen Creek remained stationary over the nest pit during the spawning act, not swimming over the pit while discharging the sex products. Furthermore, the pair spawned only once, after which the female immediately covered the eggs, using the undulating movements described below.

POST-SPAWNING BEHAVIOR

Immediately after spawning the female eastern brook trout began what may be termed a "post-nuptial" dance. This is beautiful to watch and is quite a different method of covering the eggs than that used by rainbow or steelhead, cutthroat, or Atlantic salmon. While Smith (1941) described this process from a blind above the water, I am able to add more details. After dropping the eggs, the female immediately began a sinuous, weaving motion, using the ventral tips of the caudal and anal fins to roll gravel gently into the nest over the eggs that could be clearly seen on the bottom of the pit. The motion consisted of weaving her head and caudal fin gently back and forth in the same direction, with the head raised high over the redd and the anal and lower tip of the caudal working over the gravel adjacent to the eggs. That she knew precisely the spot where she had dropped the eggs, was evidenced by the fact that not once did she work the caudal directly over the eggs themselves. Her anal fin was curved into a somewhat shovel-like position into the gravel and pushed pebbles slowly into the egg pit. The gravel was small, mostly around one-quarter of an inch in size, and usually only a single pebble or two moved with each individual sweep. She had the eggs completely covered in four minutes. She circled the pit in this manner with the head directed outward and her caudal portions inward, near but not over the eggs, for around half an hour. After 30 minutes, and after she must have known the eggs were deeply covered, she would occasionally begin the characteristic digging or cutting movements upstream some eight inches above the pit where she last deposited the eggs. By 1.45 p.m., she was regularly cutting a new nest and had ceased egg-covering movements.

While covering the eggs, she was most aggressive in driving away immature eastern brook and rainbow trout. She would attack them viciously at times, opening her mouth to bite them. The male, on the other hand, seemed quite docile during this period and hung around the downstream edge of the nest doing little to aid the female in driving other fishes off the nest area. Some 10 to 15 minutes after the spawning act, the male that had mated with her departed for some other place in the pool while she continued to cover the eggs. During the process of covering the eggs, one of the large male brown trout came cruising by the redd. She ignored him, but she drove off all other fish that attempted to come near. The next morning the redd was beautifully rounded and topped with small pebbles.

None of the other fish in the pool were allowed close enough to the nest by the female at any time to secure eggs. This observation would tend to give assurance of minimal losses by predation during the spawning process. Some of the smaller males were frequently aggressive, and much of the female's time was spent fighting them off. One of the small males was observed to grab her caudal peduncle in his jaws, even though he was much smaller in size. This I judge to be part of the courting act rather than an act of aggression.

The actual spawning act by the same pair was observed again at 11.05 a.m. on October 11. This time the nest had been dug about 12 inches upstream from where she spawned on October 10. Observations were started at 10.50 a.m. It was possible to tell that she was almost ready to spawn because she was feeling deeply into the pit with her anal fin and still turning on her side, and digging once or twice a minute. The same behavior occurred after spawning as was observed the day before. The female immediately started the beautiful undulating motion to cover the eggs. The same tagged male mated with her and this time he remained only three or four minutes, after which he departed. After spawning he became far less aggressive towards other males. Again after her mate departed, the small eastern brook males, some five of them, gathered around evincing interest in her.

Once the female, in between undulations in pushing the gravel over the eggs, swam over and rubbed her fins over the male with whom she had just mated, seemingly to perform an act of courtship toward him. No other males were in on the spawning process other than the large male that attended her at all times, except immediately after spawning.

The smaller males in the pool became quite excited just before the actual spawning act and vigorously attempted to intrude into the nest area. What attracted them is not known, but possibly it was the motions of the female that indicated that spawning was about to occur. In any case, the male was kept busy driving smaller males away.

On October 11, she had deposited her eggs in much larger gravel but, even so, had no difficulty in covering them deeply. She never turned on her side and cut vigorously in the area in which the eggs were laid, although she would occasionally go through a sort of half-hearted cutting motion a foot or so upstream from the point where the eggs were deposited.

WATER TEMPERATURES DURING SPAWNING PERIOD

Air and water temperatures are continuously recorded at Sagehen Creek with a two-pen, Taylor recording thermometer. Daily maximum and minimum water temperatures between August 31 and October 25 are presented in Figure 3. Highly-colored male brook trout were observed in the tank pool as early as September 15. Peak of spawning occurred between October 1 and October 15, after minimal water temperatures had dropped to between 37 and 44 degrees F. Daily mean water temperatures ranged between 43 and 46 degrees F. during this period. It is my observation that male trout mature sexually before females, and if the date of appearance of ripe males in Sagehen Creek is taken as the start of the spawning season, then September 15 could be considered the beginning of breeding in 1959. Female brook trout stayed near the redds until around October 25, in the post-spawning period after the males had lost interest and departed. The full spawning season could be estimated to run from September 15 until October 25. In Figure 3, it will be noted that a rapid drop in temperature occurred starting on September 15. This may have served as a releasing mechanism, for spawning activities were initiated immediately afterward.

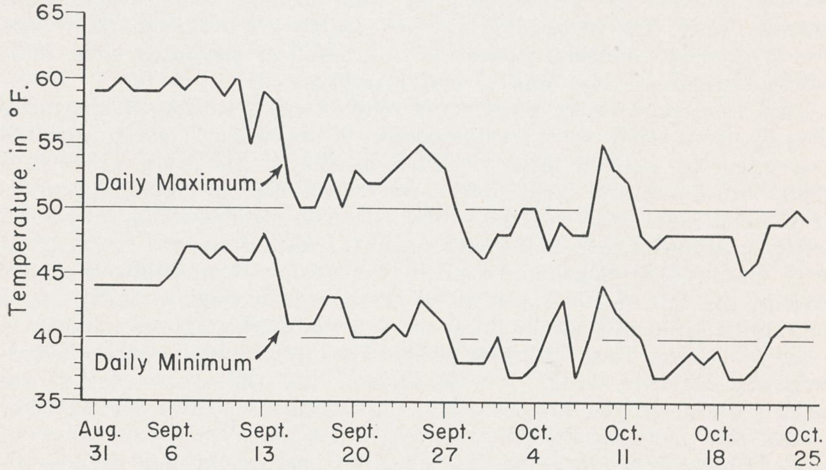


FIGURE 3. Water temperatures—Sagehen Creek August 31 to October 25, 1959.

Fabricius and Gustafson (1954) noted that the Arctic char spawned at temperatures ranging between 38.3 and 54.5 degrees F. (3.5 and 12.5 degrees C., respectively); Jones and King (1949), in work on Atlantic salmon, reported that spawning took place between 36 and 42 degrees F.

WATER VOLUME DURING SPAWNING

A gaging station is operated jointly on Sagehen Creek by the University of California and the Water Resources Division of the U. S. Geological Survey, using a Leopold-Stevens A35 gage-height recorder. It is located approximately one-quarter of a mile below the observation tank. Discharges between September 1 and October 31 were quite even for the most part, ranging between 1.4 and 1.9 cubic feet per second (c.f.s.). An early fall storm on September 18 raised the flow suddenly to 6.1 c.f.s., but by September 21 it had dropped back to 1.9 c.f.s. Over the peak of the spawning period between October 1 and 15, discharges ran between 1.7 and 1.9 c.f.s. In other words, volume of flow was low and even, without any disturbance by severe flooding.

DISCUSSION

The main environmental factors inducing the appropriate physiological condition for spawning in an adult brook trout are day length and water temperature. Selection of the actual spawning site is determined by visual stimuli of particle sizes seen by the female, possibly coupled with water movements. Actual mating behavior, on the other hand, is related to exchange of various physical stimuli or releasers during fighting and courtship.

Clear experimental evidence is presented by Fabricius and Gustafson (1954), indicating that nest-digging movements of the Arctic char (*Salvelinus alpinus*) may be released by visual stimuli. These workers covered suitable spawning gravel areas with smooth glass plates, and the females performed normal digging movements and spawned only on that portion of the plates that were located over suitable-sized gravel. Large, flat stones laid in the bottom—even though they were not covered by the glass plates—were ignored as spawning sites, indicating that gravel size was of major importance.

Just what part water movements play in the selection of spawning sites by trout, char, or Atlantic salmon is uncertain. The experiments just cited, as well as those reported by Jones and King (1949 and 1950) and Jones and Ball (1954), were conducted in aquaria or tanks of various types with surface current speeds ranging from 1.0 to 1.5 feet per second. Some half-dozen natural nests of eastern brook trout were observed in Sagehen Creek in the open stream below the tank area in the fall of 1959, and all of these were located in fairly rapid currents and usually at the lower ends of pools where there was gravel of suitable size. That this species spawns successfully in lakes (Needham and Sumner, 1941) is well known, and the areas selected are usually those gravel beaches where upwelling seep-water occurs. The reason that most species of trout select the lower ends or "tails" of pools is because the large amount of water passing through the gravels assures the eggs a constant supply of well-aerated water during incubation. As pointed out by Fabricius and Gustafson (1954), one of the most important functions of the nest-digging movements is to increase the permeability of the bottom materials by removal of loose, fine materials that would tend to clog the spaces between the stones and thus reduce water circulation around the eggs. They say (pp. 95 and 96), "deposition of the eggs in a permeable material is secured both by a mechanism leading the female to a place where the bottom has this character, and by instinctive movements which further increase the permeability of the material at the chosen nest site. The anchoring also cooperates in securing the deposition of the eggs in a permeable material, for this act, which immeditely precedes egg-laying, can be performed only at a place where the crevices are so deep that the anal fin of the female can sink down in them.''

In the ''crouch'' or ''anchoring'' of the female eastern brook trout observed in Sagehen Creek, it was noted that once a fairly well-formed pit had been dug, she appeared to test its depth frequently with her anal fin, moving it slowly over the gravel in the bottom by arching her back but without giving the sign stimulus for the actual spawning act. Just prior to the first act, she seemed to push the middle portion of the anterior rays of her anal fin rather constantly, for several moments at a time, against one of the larger stones in the deepest part of the redd. The tip of the fin, in this instance, was out of sight in the deepest pocket. She seemed to repeatedly ''test'' the character of the pit as to depth, width, and other characteristics. Within a few moments after this behavior, the actual breeding act was observed.

Dr. J. W. Jones wrote as follows (March 3, 1960; personal communication) regarding the use of large stones in a bed by the female:

''Trout and salmon females spend a great deal of time placing two or more larger stones in a suitable position at the bottom of the bed in between which the anal fin fits snugly when the female is crouching. I feel certain that the female positions these so that her eggs will pass into the crevice in between these large stones.'' While the female I observed did not attempt, apparently, to actually position larger stones in the bed, it was noted that she utilized the larger stones already present by carefully making the deepest part of the pit just in front of one or two such stones, and in front of which her anal fin fitted ''snugly''. This exemplifies the extreme care with which each pit is prepared by the female for the reception of the eggs.

The most complete discussion of the various stimuli involved in breeding of salmonids is found in papers by Fabricius and Gustafson (1954) and Jones and Ball (1954). Fabricius and Gustafson, in discussing the findings of Jones and Ball, point out that while there are many striking similarities between the behavior of brown trout and the Arctic char, there are also some sharp differences. For instance, the Arctic char and brown trout often bite their opponents. This is also true of the eastern brook trout and also of the Atlantic salmon. Similarly, the brown trout, Atlantic salmon, and eastern brook trout spawn but once in a single pit, and the females begin to cover the eggs immediately afterward, whereas the Arctic char will perform several spawning acts in each pit. This observation is confirmed in work by Dr. Winnifred E. Frost (1956). She observed that with the eastern brook trout only a single orgasm takes place over a single pit, whereas with the Lake Widermere char (*S. alpinus*) two to seven usually occur. Frost also reports the undulating movements used by eastern brook trout to cover the eggs, stating (p. 31), ''the female moved stones as big as walnuts with her tail and covered the eggs to a depth of an inch.'' Both the eastern brook and the Arctic char use similar undulating movements to bury the eggs. The above papers each present different interpretations of courtship behavior, especially with respect to the trembling or quivering movement exhibited. Readers are referred especially to Tinbergen (1951) for the broader outlines of this process of animal behavior.

In small streams, it is easy to locate and to count redds. The shallow gravel areas in which the females dig are quite noticeable to the eye once one becomes familiar with their appearance. All sediment and silt is washed away, and they appear—when completed—as small, nicely rounded piles of clean gravel. Unworked areas, by way of contrast, appear undisturbed and darker in color from fine layers of sediments on the gravels.

Oftentimes one can locate spawning fish simply by the noise made by the females during digging operations. I have located redds of steelhead, cutthroat, brown and eastern brook trout by the noisy splashing actions of females during breeding.

Much more thorough information is needed on such details as water volumes and direction of flow through redds, size and position of gravels selected, and water temperatures during spawning. Of greater importance would be information dealing with population densities on spawning areas in relation to subsequent hatching and survival of young. Where fish are crowded on limited gravel areas, and where their density is such that late-spawning fish may dig up and destroy or make accessible to predators eggs laid by early spawning females, heavy losses result. By knowing in full the spawning requirements of each species and the optimal densities in relation to space and survival, it should be possible to install suitable spawning beds—or improvements to them—that would be utilized by the fish where such facilities are lacking, scarce, or crowded. Proof that trout can be induced to use artificially constructed redds is presented here and in a number of the papers cited.

ACKNOWLEDGMENTS

Thanks are given to Mr. Fred W. Johnson of the Sagehen Creek Station staff, who assisted the writer in construction of the two spawning beds described; and to graduate students Bob Behnke, John Hopkirk, Don Roberts, Don Seegrist, and Ted Wooster, who assisted in resetting the observation tank late in the summer of 1959. I am also indebted to Dr. Peter Marler and to Dr. Richard Gard, who read the manuscript and offered suggestions for its improvement.

SUMMARY

(1) Spawning behavior of a single pair of eastern brook trout, *Salvelinus fontinalis,* was studied in Sagehen Creek, California, from an underwater observation tank.

(2) Two artificial spawning beds were constructed of gravel beside the two downstream windows of the tank. These proved most successful—the fish moving on to them promptly after they were installed. Washed gravel of walnut size and smaller was used.

(3) The pair observed was quite territorial, driving away all invaders aggressively from their nest area. No color changes were observed in the trout while assuming threat postures.

(4) Brown trout, *Salmo trutta,* stocked in the tank pool, spawned only at night, while the brook trout appeared to spawn both day and night. Rainbow trout, *Salmo gairdnerii,* did not molest the spawners at

any time, nor were they observed to attempt to eat eggs deposited in the redd.

(5) Spawning activities of the female consisted of searching for a suitable nest site, nest cutting, testing of nest site by "anchoring" or "crouching," actually spawning, and covering eggs. During the latter process the female went through a kind of a "post-nuptial" dance in which she performed a weaving, undulating movement using the ventral portions of anal and caudal fins to gently push gravel into the pit over the eggs. After actually spawning once, she immediately began to cover the eggs.

(6) The activities of the male were largely related to aggressively fighting off all intruders into the nest area and in sharing in the spawning act. He did not share in the cutting of the nest.

(7) The female, when ready to spawn, produced an appropriate signal movement when her anal fin was in the deepest part of the pit. The male swiftly took his place beside her; both opened their mouths wide and trembled while eggs and milt were emitted simultaneously. About one second was required for each of the two acts observed.

(8) The peak of the spawning period in Sagehen Creek occurred between October 1 and October 15—when daily, minimum water temperatures ranged between 37 and 44 degrees F. Volume of water flow varied from 1.7 to 1.9 cubic feet per second over the same period.

REFERENCES

Belding, David L.
1934. The spawning habits of the Atlantic salmon. Amer. Fish. Soc., Trans., vol. 64, pp. 211-218.

Berry, John
1939. Account of hatching and stocking experiments. Avon Bio. Res., Ann. Rept., 1937-38, pp. 27-33.

Briggs, John C.
1953. The behavior and reproduction of salmonid fishes in a small coastal stream. Calif. Dept. Fish and Game, Fish Bull. 94, 62 pp.

Cramer, Frederick K.
1940. Notes on the natural spawning of cutthroat trout *(Salmo clarkii clarkii)* in Oregon. Sixth Pac. Sci. Cong., Proc., vol. 3, 1939, pp. 335-339.

Fabricius, Eric
1950. Heterogeneous stimulus summation in the release of spawning activities in fish. Inst. Freshwater Res., Drottningholm, Rept. no. 31, 1949, pp. 57-99.
1953. Aquarium observations on the spawning behavior of the char, *Salmo alpinus*, L. Inst. Freshwater Res., Drottningholm, Rept. no. 34, 1952, pp. 14-48.

Fabricius, Eric, and Karl-Jakob Gustafson
1954. Further aquarium observations on the spawning behavior of the char, *Salmo alpinus* L. Inst. Freshwater Res., Drottningholm, Rept. no. 35, 1953, pp. 58-104.

Frost, Winnifred E.
1956. 24th Ann. Rept. of the Freshwater Biol. Assoc. (of the British Empire) for year ended 31 March, 1956, 65 pp.

Greeley, John R.
1932. The spawning habits of the brook, brown, and rainbow trout and the problem of egg predators. Amer. Fish. Soc., Trans., vol. 62, pp. 239-248.

Hazzard, A. S.
1932. Some phases of the life history of the eastern brook trout, *Salvelinus fontinalis* Mitchell. Amer. Fish. Soc., Trans., vol. 62, pp. 344-350.

Hobbs, Derisley F.
1937. Natural reproduction of quinnat salmon, brown and rainbow trout in certain New Zealand waters. New Zealand Marine Dept., Fish Bull. 6, 104 pp.

Jones, J. W.
1959. The salmon. Collins, London, 198 pp.
1960. Personal correspondence.

Jones, J. W., and G. M. King
1949. Experimental observations on the spawning behavior of the Atlantic salmon (*Salmo salar* L.). Zool. Soc. London, Proc., vol. 119, pp. 13-48.
1950. Further experimental observations on the spawning behavior of the Atlantic salmon (*Salmo salar* L.). Zool. Soc. London, Proc., vol. 120, pp. 317-323.

Jones, J. W., and J. N. Ball
1954. The spawning behavior of brown trout and salmon. Brit. Jour., Animal Behavior, vol. 2, pp. 103-114.

Needham, P. R.
1956. The Sagehen Creek experimental wildlife and fisheries project. Amer. Inst. Biol. Sci. Bull., Nov. 1956, 3 pp.
1959. New horizons in stocking hatchery trout. Trans. 24th N. Amer. Wildl. Conf., pp. 395-406.

Needham, P. R., and A. C. Taft
1934. Observations on the spawning of steelhead trout. Amer. Fish. Soc., Trans., vol. 64, pp. 332-339.

Needham, P. R., and Frank Sumner
1941. Fish management problems of high, western lakes with returns from marked trout planted in Upper Angora Lake, California. Amer. Fish. Soc., Trans., vol. 71, pp. 249-269.

Needham, P. R., and T. M. Vaughn
1952. Spawning of the Dolly Varden in Twin Creek, Idaho. Copeia, no. 3, pp. 197-199.

Needham, P. R., and A. C. Jones
1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology, vol. 40, no. 3, pp. 465-474.

Schultz, Leonard P., and students
1935. The breeding activities of little redfish *Oncorhynchus nerka*, a land-locked form of the sockeye salmon. Jour. Pan. Pac. Res. Inst., vol. 10, no. 1, pp. 67-76.

Smith, Osgood R.
1941. The spawning habits of cutthroat and eastern brook trouts. Jour. Wildl. Mgt., vol. 5, no. 4, pp. 461-471.
1944. Returns from natural spawning of cutthroat trout and eastern brook trout. Amer. Fish. Soc., Trans., vol. 74, pp. 281-296.

Stuart, T. A.
1953. Spawning migration, reproduction, and young stages of the loch trout (*Salmo trutta* L.). Rept. No. 5, Freshwater and Salmon Fish. Res., Home Dept., Scotland, 39 pp.

Tinbergen, N.
1951. The study of instinct. Oxford, Univ. Press, 288 pp.

o

33379 1-61 425 *printed in* CALIFORNIA STATE PRINTING OFFICE